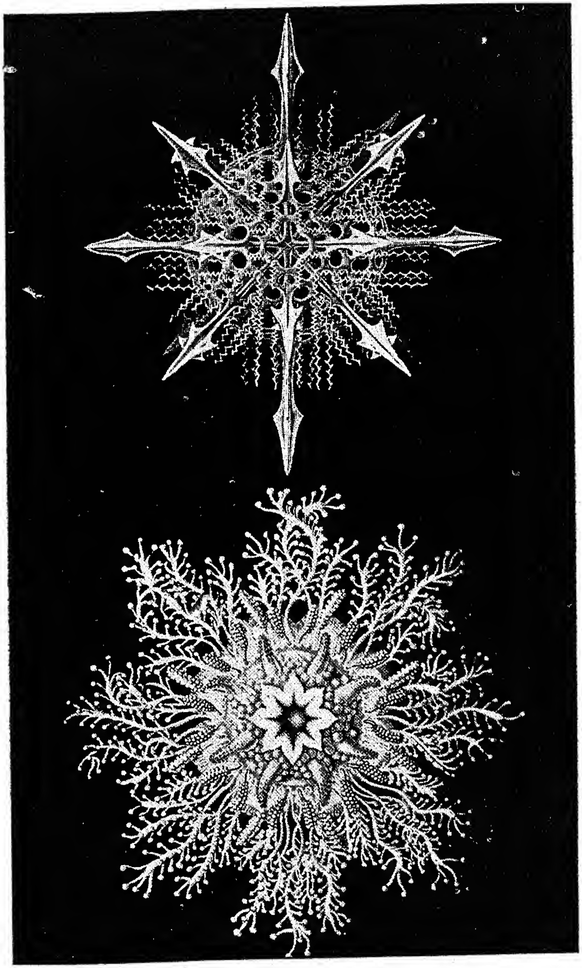

Radiolarian and Siphonophore, Makers of Much of the Ocean Bed.

THE SCIENCE-HISTORY OF THE UNIVERSE

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THE SCIENCE-HISTORY OF THE UNIVERSE

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THE SCIENCE-HISTORY OF THE UNIVERSE

VOLUME II

GEOLOGY

By HAROLD E. SLADE
AND
W. E. FERGUSON

CONTENTS

GEOLOGY

CHAPTER I

MYTHS OF THE EARTH'S ORIGIN

THIS Earth whereon man lives, by which he has his being and to which he returns, was to the ancients a riddle inexplicable. What mighty hand, they wondered, could have upreared the mountain peaks whose glittering summits pierced the very clouds; what fearsome figure lurked in the volcanic forge where subterranean rumblings seemed to tell of life within; what stupendous power could evoke from nowhere the shrieking tempest which destructively could mock the puny efforts of the world of men? Answers there must be, and the beginnings of Geology are the cosmogonies devised by inexact observation and by fancy to propound a suitable reply.

The earliest efforts at the interpretation of nature found their expression in the mythologies and cosmogonies of primitive peoples, which varied in type from country to country, according to the climate and other physical conditions under which they had their birth. Geological speculation may thus be said to be traceable in the mental conceptions of the remotest pre-scientific ages.

Among these first gropings after truth the Babylonian account of the Creation holds an honored place, not only by reason of its completeness, but also because modern knowledge of it is gained from tablets of extreme antiquity, tablets which in themselves hold high rank in the

records of historical importance. With the Babylonians Creation begins with Chaos. The gods arose before heaven and earth had taken shape, while the tumultuous floods of oceans were still intermingled in the universal chaos. The gods chose Marduk to be their champion against Tiamat, the disturbing, chaotic ocean-flood. Marduk armed himself with lightning flash and thunderbolt and called the winds to his assistance. Marduk vanquished Tiamat and divided his corpse into two parts; from the one part he created the heavens and from the other the earth and the sea. Marduk peopled the heavens with stars, the dwellings of the great gods. Then followed the creation of plants and animals and finally the creation of the two first human beings out of clay.

The Mosaic account of the Creation far excels the Babylonian in its noble simplicity and in the strength and beauty of the language. In it the origin of the world, of the earth and its inhabitants, is represented as the work of a personal God. The Mosaic account, which is especially distinguishable among early cosmogonies by its recognition of the existence of light before the actual orb of the Sun was visible (due to dense aqueous atmosphere) was incorporated in the Bible of the Christian Church, and, unfortunately, was regarded as being a scientific treatise, in addition to its recognized character as a statement of Creation designed to teach Man about his origin and his personal relations to his Creator. This misconception of the purpose of the early chapters of the Book of Genesis retarded the progress of Geology for many centuries, as theologians sought to suppress all scientific centuries, as theologians sought to suppress scientific writings which did not harmonize with their interpretation.

The Greeks were less inclined than the Oriental nations to interweave the ideas of mythology, religion and science. They viewed natural events from a more critical standpoint and treated them as subjects of philosophical speculation. In their early Ionian days, however, their understanding of the cosmogony was comparatively primitive,

tho heightened and made of interest by the imaginative force with which they peopled that portion of the Earth's surface which was remote to them.

Homer's contributions to ancient geography were large

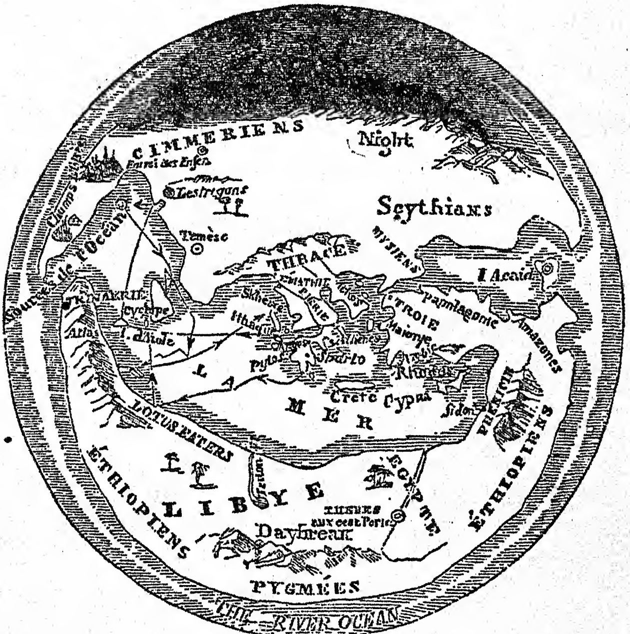


Fig. 1 —The World According to Homer.

—and curious, but cosmogonical ideas do not seem to have occurred to him. He presupposed that the earth was flat, and that the sun truly sank into the sea. Hesiod, in his 'Theogony,' tells of the birth of the world and Time 'Chronos,' he describes the wars of the older and the Olympian gods, but he seems to have accepted the prev-

alent conception of the world as a flat disk with Greece in the center.

These early cosmogonies, while differing greatly in style, elaboration of detail and the degree to which they expressed the conceit of the author, had certain points in common. They all agree on successive alternate creations and destructions of the world. These speculations were closely interwoven with their religion, as were all the sciences, and the destructions were supposed to come when man's sin had become intolerable to the then ruling deity. The following creation included a race of men free from sin and taint of all kinds, who immediately proceeded to gradually degenerate. In the "Institutes of Menu," the sacred volume of the Hindus, is the following verse:

> "There are creations also and destruction of worlds innumerable. The Being, supremely exalted, performs all this with as much ease as if in sport, again and again, for the sake of conferring happiness."

"There are at the same time such puerile conceits and monstrous absurdities in this cosmogony," says Sir Charles Lyell in his famous 'Principles of Geology,' "that some may be disposed to impute to mere accident any slight approximation to truth or apparent coincidence between the Oriental dogmas and observed facts. This pretended revelation, however, was not purely an effort of the unassisted imagination nor invented without regard to the opinions and observations of naturalists. There are introduced into it certain astronomical theories, evidently derived from observation and reasoning. Thus, for instance, it is declared that, at the North Pole, the year was divided into a long day and night and that their long day was the northern, and their night the southern course of the Sun; and to the inhabitants of the Moon, it is said, one day is equal in length to one month of mortals."

The Brahmins and Chinese corroborated this notion of successive creations and destructions and also described a great flood. Plutarch tells us that this was the subject

of one of the famous hymns of Orpheus. In his verses he sets a definite period for each cycle or life of a world. Orpheus assigned 120,000 years while Cassandra took it to be 360,000 years.

The Egyptian priests were aware not only that the soil beneath the plains of the Nile, but that also the hills bounding the great valley, contained marine shells, and it could hardly have escaped the observation of Eastern philosophers that some soils were filled with fossil remains, since so many national works requiring extensive excavations were executed by Oriental monarchs in very remote eras.

Thales of Miletus, the contemporary of Crœsus and Cyrus, who considered that everything, animate and inanimate, was derived from water, added but little to early cosmology, save that his theory presupposed a condition of constant flux. His gifted scholar, Anaximander (circa 611 B.C.), arrived at a higher conception of Nature. He depicted an infinite, all-pervading primeval substance, possessing an inherent power of movement from the first. The energy of this primeval matter determined heat and cold, and the mixture of these conditions gave origin to the development of fluid; the earth, the air and a surrounding circle of fire differentiated from the fluid state. The stars sprang from fire and air; the earth rested in the center of the whole universe, and, under the influence of the sun, brought forth the animals which inhabit it. These, including human beings, were at first fish-like in form, consistent with the semi-fluid state of their environment.

Xenophanes of Colophon (614 B.C.) is reported by later writers to have observed the shell remains of pelagic mollusca on mountains in the middle of the land, impressions of laurel leaves in the rocks of Paros, as well as various evidences of the former presence of the sea on the ground of Malta, and to have attributed those appearances to periodic invasions of the sea during which men and their dwellings must have been submerged. The historian

Xanthus of Sardis (circa 500 B.C.) also drew attention to the occurrence of fossil shells in Armenia, Phrygia and Lydia, far from the sea, and concluded that the localities where such remains occur had been formerly the bed of the ocean and that the limits of the dry land and the ocean were constantly undergoing change.

Herodotus (484 B.C.) mentioned the presence of fossil shells of marine bivalves in the mountains of Egypt and near the oasis of Ammon. From this fact, as well as from the salt constitution of the rocks, Herodotus formed the opinion that Lower Egypt had been at one time covered by the sea, and that the material carried down by the Nile had been discharged into the sea-basin between Thebes and Memphis and the present delta, and gradually filled it up. Herodotus could not form any definite opinion as to the cause of the Nile inundations, altho he gave a careful report of the hypotheses then in favor.

The Gorge of Tempe, previously referred to, also came under the notice of the Father of History. He says:

> "That the Gorge of Tempe was caused by Poseidon is probable; at least one who attributes earthquakes and chasms to that god would say that this gorge was his work. It seemed to me to be quite evident that the mountains had there been torn asunder by an earthquake."

Heraclitus (535 B.C.) thought there was in the universe nothing stable, nothing lasting. Everything was in a state of constant change, like a stream in which new wares endlessly supplant the old. For him fire was the primeval force, which unceasingly transformed itself, pervaded every portion of the universe, produced individuals and again destroyed them. Fire became the ocean, and that again earth, and the breath of life. The rising vapors burned in the air and formed the sun, which was renewed from day to day. Thus Heraclitus taught that altho the universe always had been and always would be, no portion

of it had ever been quiescent, and that from time to time a new world was constructed out of the old.

Pythagoras, who was born at Samos about the year 582 B.C., and afterward went to Crotona in Italy, is one of those eminent leaders of thought around whose name and teaching much that is mythical has gathered. "His followers," suggests Karl von Zittel in his 'History of Geology and Paleontology,' sought to explain natural phenomena chiefly by analogy with definite numerical relationships. An ordered universe depended, according to the Pythagoreans, upon the principle of numbers. According to Diogenes Laertius, Pythagoras imagined the universe in the form of a sphere. The earth was in the center and bore the axis around which the firmament revolved."

The principle of constant change taught by Pythagoras and Heraclitus was also a leading feature in the doctrines of Empedocles of Agrigentum (492-432 B.C.). Empedocles supposed that everything had its origin in, and took its components from, four elements (earth, water, air and fire); that these elements were without beginning and imperishable, but subject to never-ending change. From these elements the world at one time took shape, and it must at some future time be again dispersed. The course of the world's existence resolved itself into a history of recurring periods and phases. Geology owes one distinct step in advance to this philosopher. Whereas the Pythagoreans had conjectured the presence of a central fire in the universe, Empedocles taught that the earth's center was composed of molten material. Empedocles formed this opinion on the basis of his actual observation of the volcanic activities of Mount Etna. Tradition says that he met his death by falling into the crater of that volcano.

Plato (427 B.C.), in his Cosmology, is a follower partly of Heraclitus and partly of Anaxagoras. According to Plato, the universe is the production of divine intelligence and of the necessary development of nature. The form of

the whole universe is spherical; in the center lies the earth as a motionless sphere. An interesting account is given in the "Timæus" of a submerged Atlantic continent (Atlantis) on the other side of the Pillars of Hercules (Gibraltar). The idea of such a submerged continent has again and again received credence. In Plato's account Atlantis was larger than Asia and Libya together. It had been inhabited 9,000 years before his time, and since its destruction by earthquakes and inundations, navigation in the Atlantic had been impossible owing to the fine mud and detritus left by the vanished land. Another of Plato's theories related to the origin of rivers. He attributed them all to a common underground source.

The work of Aristotle (384-322 B.C.) marks the culminating point reached by the Greeks, both in the domain of speculative philosophy and in that of empirical observation. His treatises furnish an admirable exposition of the state of natural knowledge in his time. When he wrote, the geocentric view of the universe was still publicly accepted without question. But he had firmly grasped certain truths regarding the globe, which, tho taught long before by some of his predecessors, were not yet generally admitted. Accepting the common belief that the world consisted of four elements, he looked on these as arranged according to their relative densities. He said:

> "The water is spread as an envelope round the earth; in the same way above the water lies the sphere of air, while outside of all comes the sphere of fire."

With regard to the surface of the planet, Aristotle had formed some sagacious conclusions, tho mingled with certain of the misconceptions that were prevalent in his time. He remarks that earthquakes are due to a commingling of moist and dry within the earth.

> "Of itself, the earth is dry, but from rain it acquires much internal humidity. Hence when it is warmed by the sun and by the internal heat, wind is produced both within and without its mass. Wind, being the

lightest and most rapidly moving body, is the cause of motion in other bodies; and fire, united with wind, becomes flame which is endowed with great rapidity of motion. It is neither water nor earth which causes an earthquake; it is the wind when what is vaporized outside returns into the interior."

Aristotle regarded earthquakes and volcanic eruptions as closely related phenomena. He states that it had been observed in some places that an earthquake has continued until the wind from the interior has rushed out with violence to the surface, as had then recently happened at Heracleia on the Euxine, and before that event at Hiera (Volcano), one of the Lipari Isles. At this latter locality the ground rose up with a great noise and formed a hill that broke up and allowed much wind to escape from the fissures, together with sparks and cinders which buried the whole of the neighboring town of the Liparans. The shock was even felt in some of the towns on the opposite mainland of Italy.

Aristotle was further led to propose an explanation of the great heat that forms part of the volcanic phenomena.

> "The fire within the earth can only be due to the air becoming inflamed by the shock, when it is violently separated into the minutest fragments. What takes place in the Lipari Isles affords an additional proof that the winds circulate underneath the earth."

This idea that volcanic action was mainly due to the movement of wind imprisoned within the earth obtained wide credence in antiquity. Æolus, the god of the winds, was believed to have his abode under the so-called Æolian Isles, which are all of volcanic origin and among which eruptions have been taking place since before the dawn of history.

This tireless observer of antiquity also discusses the phenomena presented by rivers and shows considerable acquaintance with the drainage system on the north side of the Mediterranean basin. He criticizes previously ex-

pressed opinions as to the source of rivers, particularly ridiculing the suggestion of Plato that all rivers flow directly from a vast mass of water under the earth. He appears to have held the opinion that just as the vaporized moisture in the atmosphere is condensed by cold and falls in drops of rain, so the moisture beneath the earth is similarly condensed and forms the sources of rivers.

He states that the mountains, by their cold temperature, condense the atmospheric moisture and receive a vast quantity of water, so that they may be compared to an enormous suspended sponge. He shows by geographical illustrations, drawn from Asia and the Mediterranean basin, that the largest rivers descend from the loftiest ground, where the water accumulates in numberless channels. He admits the possible existence of underground lakes from which rivers may issue and alludes to the disappearance of some streams into subterranean channels.

No writer of antiquity has expressed himself more philosophically than Aristotle regarding the past vicissitudes of the earth's surface. Having studied so carefully the operations of the various agents that are now modifying that surface, he recognised how greatly the aspect of the land must have been transformed in the course of ages. His remarks on this subject have a strikingly modern tone. He contemplates the alternations of land and sea and furnishes illustrations of them, much as a geologist of to-day might do.

> "The sea now covers tracts that were formerly dry land, and land will one day reappear where we now find sea.
>
> "These phenomena escape our notice because they take place successively during periods of time, which, in comparison of our brief existence, are immensely protracted. Whole nations may disappear without any recollection being preserved of the great terrestrial changes which they have witnessed from beginning to end."

The deluge of Deucalion, Aristotle suggests, affected Greece only, and principally the part called Hellas, and it arose from great inundations of rivers during a rainy winter. But such extraordinary winters, tho after a certain period they return, do not always revisit the same places. He concludes with these remarkable words:

> "It is clear that, as time never stops and the universe is eternal, the Tanais and the Nile, like all other rivers, have not always flowed; the ground which they now water was once dry. But if rivers are born and perish, and if the same parts of the land are not always covered with water, the sea must undergo similar changes, abandoning some places and returning to others, so that the same regions do not remain always sea or always land, but all change their condition in the course of time."

The great advances along certain lines of thought under the impetus of the Roman leadership infused a more realistic spirit into the investigations of all great workers in Natural Science, especially those interested in Geology. Among the latter the first place must be given to the historian and traveler Strabo (circa 63 B.C.), whose geography, comprising seventeen volumes, was written about the beginning of the reign of Tiberius. It contains not a few important facts in regard to the general effects of subterranean energy.

Thus he cites a number of earthquakes by which chasms in the ground were formed, thousands of people were destroyed and cities were swallowed up. He also gives some information regarding volcanic eruptions which had taken place within the historical period in the Mediterranean region. In his time Mount Vesuvius was not only quiescent, but was not known ever to have been active. His quick eye, however, detected the true origin of the mountain. From the aspect of its summit he inferred that it was once a volcano, with live craters which had become extinct on the failure of the subterranean fuel, and he

compared its slopes to the ground around Catania, where the ashes thrown out by Etna have formed an excellent soil for vines. He recognised the truly volcanic nature of the whole district from Etna to the Phlegraean Fields, under which Typhon, as Pindar sang, lay crushed on his burning bed. In his excellent account of the ascent of Etna, Strabo compares the molten lava to a kind of black mud which, liquefied in the craters, is ejected from them and flows down the sides of the mountain, cooling and congealing in its descent, until it becomes a motionless dark rock like millstone. He also attributes earthquakes to the force of winds pent up within the earth. The doctrine that volcanoes are safety valves, therefore, which has been quoted as a modern idea, is prior in origin to the beginning of the present era.

The oceanic islands far from any mainland have, according to Strabo, been thrown up by subterranean fires. In support of this view Strabo cited the case of a volcanic eruption in the year 196 B.C. between Thera and Therasia. For four days flames rose from the ocean, and as these died down it was observed that a new island had been formed, measuring twelve stadia in circumference. Strabo is therefore rightly regarded as the father of modern theories of mountain-making. He pointed out that Sicily in his time was less frequently disturbed by earthquakes than it had been in previous ages before volcanic discharges were known in the district, and he correlated the comparative tranquillity of the ground with the means of escape afforded for explosive underground vapors by the volcanic vents that had opened at Etna, in the Lipari Isles, and in Ischia. It speaks highly for Strabo's powers of observation that he should have recognised in Vesuvius a volcanic mountain, altho it was then quiescent.

Probably the most acute scientific observer of Roman times was Seneca, the physician of the Emperor Nero (2 B.C.-65 A.D.). Quite recently Nehring has placed the importance of the work of Seneca in its true light. The

"Quæstiones Naturales" contain detailed communications about earthquakes, volcanoes and the constructive and destructive agencies of water. Seneca explains earthquakes partly as a result of the expansion of gases accumulated in the earth, partly by the collapse of subterranean cavities. He appears to have been much impressed by the earthquake which did so much damage in Campania on February 5th, 63 A.D., for he refers to it again and again, and furnishes from the lips of eye-witnesses some interesting particulars regarding it. Thus he tells how a flock of 600 sheep were killed in the district of Pompeii, a fate which he attributes to the rise of pestilential vapors from the ground. He was informed by a most learned and serious friend that when he was in the bath the tiles on the floor were separated from each other and were then driven together again, while the water at one moment sank through the opened joints of the pavement and thereafter boiled up again and was jerked out. The philosopher's account is the earliest detailed description of an earthquake which has come down to us.

Seneca regarded volcanic eruptions simply as an intensified form of the same series of phenomena and volcanoes themselves as canals or vents between local sub-terrestrial reservoirs of molten material and the earth's surface. In speaking of two outbreaks at Santorin, he remarks that an island rose out of the sea by protracted eruptions from below, and he notes that the internal fire is neither extinguished by the weight of the superincumbent depth of sea nor prevented from rushing to a height of a couple of hundred paces above the water. He speaks of Ætna having sometimes abounded in much fire and thrown out a great deal of burning sand, day being turned into night, to the terror of the population. On such occasions thunder and lightning are said to have abounded, but these came from the concourse of dry materials and not from ordinary clouds, of which probably there were none in such a raging heat of air—a shrewd anticipation of the

modern distinction between ordinary atmospheric electric discharges and those evoked during the ejection of vapors, gases, dust and stones from a volcanic orifice.

The earth to him, however, was primitively a watery chaos, and it is more especially in his treatment of the action of water in dissolving and carrying away rock-material, together with his explanation of the origin of sediments and deltas, that Seneca has shown his remarkable insight and sound judgment. His ideas on the origin of river water were no further advanced than those of his predecessors. He agreed with them in attributing all rivers to an inexhaustible internal source. Water being one of the four elements forms a fourth part of nature. Why then, he argued, should there be surprise if it can always keep pouring out? Just as in the human body there are veins which when ruptured send forth blood, so, he thought, in the earth there are veins of water which are found even in the driest places, at depths of two or three hundred feet, and which when laid open issue in springs and rivers. The water at these depths, so far below the limits to which rain can moisten the earth, is not regarded by him as of atmospheric origin, but living water (*aqua viva*).

The learned historian, Pliny the elder (23-79 A.D.), has handed down to us a compendium that embraces the whole scientific knowledge of antiquity. By a tragic decree of fate this untiring student and naturalist met his death while engaged in observing the grandest geological event of historic antiquity—the first outbreak of Vesuvius in the year 79 A.D. He died in the open field, probably suffocated by the volcanic vapor and ash. His corpse was found unharmed three days later, when the darkened sky finally became clear. The younger Pliny's vivid description of the eruption of Mount Vesuvius and the accompanying earthquake is one of the most remarkable literary productions in the domain of Geology.

CHAPTER II

THE BEGINNINGS OF MAP-MAKING

IN the ancient records there is considerable doubt as to who were the earliest voyagers. Some authorities uphold the claims of the Greeks, some the Phenicians, others the Egyptians and still others the Chinese. Advocates of the Chinese claim base their conclusion on the location of the Ark of Noah. It is alleged that the ark rested on one of the mountains of Armenia and that Scythia was the first land to be inhabited, it being of high altitude and therefore the first to appear after the flood. But such an argument, based upon a local tradition, not upon scientific evidence, has little force.

Mankind—at least that portion whose history is familiar—dwelt upon the borders of an inland, mediterranean sea. They had never heard of such an expanse of water as the Atlantic and certainly had never seen it. The land-locked sheet which lay spread out at their feet was at all times full of mystery and often even of dread and secret misgiving. Those who ventured forth upon its bosom came home and told marvelous tales of the sights they had seen and the perils they had endured. Homer's heroes returned to Ithaca with the music of the sirens in their ears and the cruelties of the giants upon their lips. The Argonauts saw whirling rocks implanted in the sea, to warn and repel the approaching navigator, and as if the mystery of the waters had tinged with fable even the dry land beyond it, they filled the Caucasus with wild stories

of enchantresses, of bulls that breathed fire and of a race of men that sprang, like a ripened harvest, from the prolific soil. If the ancients were ignorant of the shape of the earth, it was for the very reason that they were ignorant of the ocean. Their geographers and philosophers, whose observations were confined to fragments of Europe, Asia and Africa, alternately made the world a cylinder, a flat surface begirt by water, a drum, a boat, a disk. The legends that sprang from these confused and contradictory notions made the land a scene of marvels and the water an abode of terrors.

It is now generally conceded that the date of the maritime enterprises which rendered the Phenicians famous in antiquity must be fixed between the years 1700 and 1100 B.C. The renowned city of Sidon was the center from which their expeditions were sent forth. About 1250 B.C. their ships ventured cautiously beyond the Straits of Gibraltar and founded Cadiz upon a coast washed by the Atlantic. A little later they founded establishments upon the western coast of Africa. Homer asserts that at the Trojan War, 1194 B.C., the Phenicians furnished the belligerents with many articles of luxury and convenience and their ships brought gold to Solomon from Ophir in 1000 B.C.

About the period of Tyre's greatness (600 B.C.) the Phenicians, tho under Egyptian commanders, appear to have succeeded in the circumnavigation of Africa. The enterprise was undertaken by order of Necho, king of Egypt, and is commented on by Herodotus as follows: "Having in this manner consumed two years, in the third they passed the Pillars of Hercules and returned to Egypt. This story may be believed by others, but to me it appears incredible, for they affirm that when they sailed round Libya they had the sun on their right hand."

In the time of Herodotus the Greeks were unacquainted with the phenomenon of a shadow falling to the south, one which the Phenicians would naturally have witnessed

had they actually passed the Cape of Good Hope, for the sun would have been on their right hand, or in the north, and would thus have projected shadows to the south. "As this story was not one likely to have been invented in the time of Necho," suggests F. B. Goodrich in his 'Man Upon the Sea,' from which some of these adventures are condensed, "it is the strongest proof that could be adduced of the reality of the voyage.

"The first maritime adventure among the Greeks which lays any claim to authenticity, and the most celebrated in ancient times, is the expedition of the Argonauts to Colchis. The date of the expedition, if it took place at all, may be safely fixed at the year 1250 B.C. A theory propounded by Sir Isaac Newton would connect it with the year 937, but this is regarded with less favor than the earlier date. Its alleged object was the Golden Fleece, but what this was can only be conjectured."

Jason, the son of the King of Thessaly, being deprived of his inheritance and having resolved to seek his fortune by some remote and hazardous expedition, was induced to go in quest of the Golden Fleece in Colchis. He enlisted fifty men and employed Argus to build him a ship, which from him was called Argo, the adventurers being named Argonauts.

The Argonauts started their voyage from Iolcos in Thessaly, and with a south wind sailed east by north. The narrative of the expedition is full of wonders. They landed at the Island of Lemnos, where they found that the women had just murdered their husbands and fathers.

The Argonauts supplied the place of the assassinated relatives, and Jason had two sons by one of the bereaved Lemnians. When the vessel arrived at the entrance to the Euxine—the narrow strait now called the Bosphorus—they built a temple and implored the protection of the gods against the Symplegades, or Whirling Rocks, which guarded the passage. A seer named Phineas was con-

sulted upon the probability of their sailing through unharmed. The rocks were imagined to float upon the waves, and, when anything attempted to pass through, to seize and crush it.

Phineas advised the loosing of a dove and to judge from its fate of the destiny reserved for them. They did so, determined to push boldly on if the bird got through in safety. The pigeon escaped with the loss of some of its tail-feathers. The Argo dashed onward and cleared the formidable rocks with the loss of a few of its stern ornaments.

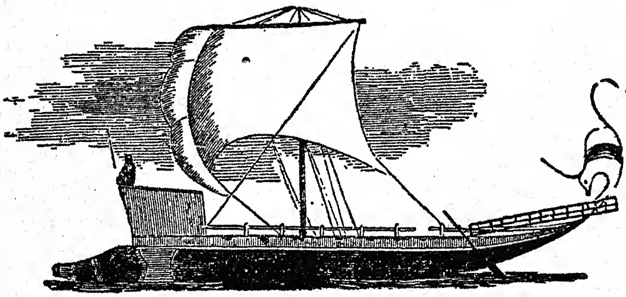


Fig. 2 —The 'Argo,' from an Ancient Bas-relief.

From this time forward, the legend adds, the Symplegades remained fixed and were no longer a terror to navigators. The Argonauts, after entering the Black Sea, sailed due east to the mouth of the River Phasis, now the Rione. Æetes, the king, promised to give Jason the fleece upon certain conditions. These he was enabled to fulfil by the aid of Medea, a sorceress and daughter of Æetes. They then fled together to Greece. This route followed by the Argonauts upon their return is differently given by the various poets who have told the story and the commentators who have illustrated it.

The Greeks, like the Hebrews, were ignorant of the real figure of the earth. It is in Homer that is found the first

written trace of the widely prevalent idea that the earth is a flat surface begirt on every side by the ocean. This was a natural belief in a region almost insular, like Greece, where the visible horizon and an enveloping sea suggested the idea of a flat circle. Homer took the lead among the poetic geographers of Greece, and his authority gave to the subject a fanciful cast, the traces of which are not yet obliterated. Beneath the earth he placed the fabled regions of Elysium and Tartarus; above the whole rose the grand arch of the heavens, which were supposed to rest on the summits of the highest mountains. The sun, moon and stars were believed to rise from the waves of the sea and to sink again beneath them on their return from the skies.

Homer's distribution of the land was even more fantastic. Beyond the limits of Greece and the western coasts of Asia Minor his knowledge was uncertain and obscure. He had heard vaguely of Thebes, the mighty capital of Egypt, and in his verse sang of its hundred gates and of the countless hosts it sent forth to battle. The Ethiopians, who lived beyond, were deemed to be the most remote dwellers upon the habitable earth. Toward the center of Africa were the stupendous ridges of the Atlas Mountains. Homer defined the highest peak and made it a giant supporting upon his shoulders the outspreading canopy of the heavens.

The narrow passage leading from the Mediterranean to the Atlantic, and now known as the Straits of Gibraltar, was believed to have been discovered by Hercules, and the mountains on either side—Gibraltar and Ceuta—were, from him, called the Pillars of Hercules. Colchos, upon the Black Sea, was believed to be an ocean city, and here Greek fancy located the Palace of the Sea. It was here that the charioteer of the skies gave rest to his coursers during the night and from whence in the morning he drove them forth again. Colchos, therefore, was Homer's eastern confine of the globe.

On the north Rhodope, or the Riphean Mountains, were

supposed to enclose the hyperborean limits of the world. Beyond them dwelt a fabled race, seated in the recesses of their valleys and sheltered from the contests of the elements. They were represented as exempt from all ills, physical and moral, from sickness, the changes of the seasons and even from death. A race directly the converse of the ideal hyperboreans were the Cimmerians, located at the south of the Sea of Azof, who are described by Homer as dwelling in perpetual darkness and never visited by the sun. He imagines the existence of numerous other nations, who long continued to hold a place in ancient geography. The Cyclops, who had but one eye, were placed in Sicily; the Arimaspians, similarly afflicted, inhabited the frontiers of India; the pigmies, or dwarfs, who fought pitched battles with the cranes, were supposed to dwell in Africa, in India, and, in fact, to occupy the whole southern border of the earth.

"In the time of Homer," says F. B. Goodrich again, "all voyages in which the mariner lost sight of land were considered as fraught with the extremest peril. No navigator ever visited Africa or Sicily from choice, but only when driven there by tempest and typhoon, and then his woes usually terminated in shipwreck; a return was not merely a marvel but a miracle. Homer made Sicily the principal scene of the lamentable adventures of Ulysses, and sufficient traces are furnished by the Odyssey of the distorted and exaggerated notions entertained in the poet's time of the character of places reached by a voyage at sea. The existence of monsters of frightful form and size, such as Polyphemus; of treacherous enchantresses, such as Circe; of amiable goddesses, like Calypso, were prefigured by the early geographers and the location of their homes marked on the early charts. The radius of the territories described by Homer with any degree of precision was hardly three miles in length.

Hesiod, who lived a century after Homer, thus states the scientific attainments of his time: "The space between

the heavens and the earth is exactly the same as that between the earth and Tartarus beneath it. A brazen anvil, if tossed from heaven, would fall during nine days and nine nights and would reach the earth upon the tenth day. Were it to continue its course toward the abode of darkness it would be nine days and nine nights more in accomplishing the distance."

Anaximander, four hundred years after Homer, held that the earth, instead of being flat, was in the form of a cylinder, convex upon its upper surface. Its diameter was three times greater than its height and its form was

Fig. 3 —The Earth According to Anaximander.

round, as if it had been shaped by a turner's lathe. The Oracle of Delphi was the center of his system.

At a period which it is no longer possible to settle with precision, but certainly anterior to the fifth century B.C., the Carthaginians, then in the height of their maritime and commercial prosperity, ordered a navigator by the name of Hanno to make a voyage beyond the Pillars of Hercules and to found cities along the western shore of Africa. He set sail with a fleet of sixty vessels, each of which was impelled by fifty oars. He carried with him

island or a continent—he knew not which—which he called Thule.

As he found he could go no farther to the north, he spoke of this spot as Ultima Thule, an expression which has passed into the figurative language of all modern nations as one denoting any remote point. Thule is generally considered to have been Shetland, altho theories have been ardently advocated making it respectively Iceland, Sweden and Jutland.

The narrative of Pytheas, which has been thus far clear and reliable, assumes at this point a fabulous aspect. He declares that north of Thule there was neither earth, nor sea, nor air. A sort of dense concretion of all the elements occupied space and enveloped the world. He compared it to the thick, viscid animal substance called pulmo marinus, a sort of mollusk or medusa. He said that this substance was the basis of the universe, and that in it earth, air and sky hung, as it were, suspended.

This illusion has been explained by the dreary spectacle of fogs, mists, rains and tempests which at this point of his voyage must have met the gaze of the daring navigator. It would have been difficult for any mind in those early ages to have been on its guard against the sinister impressions likely to result from the contemplation of a scene so appalling. It must be remembered that Pytheas was accustomed to the pure and transparent atmosphere, the dazzling sky and the phosphorescent waters of the Mediterranean. It would have been astonishing if a man educated among the splendors of an almost tropical climate had not been oppressed by influences so gloomy.

In the year 863 a Dane of Swedish origin, named Gardar, adventurously pushing off into the Northern Ocean, discovered the island-rock whose appropriate name is Iceland. Eleven years later a navigator named Ingolf colonized the country, the colonists, many of whom belonged to the most esteemed families in the north, establishing a flourishing republic. In 877 a sailor named Gunnbjorn

saw a mountainous coast far to the west, supposed to be now concealed or rendered inaccessible by the descent of Arctic ice.

Erik the Red, who had been banished from Norway for

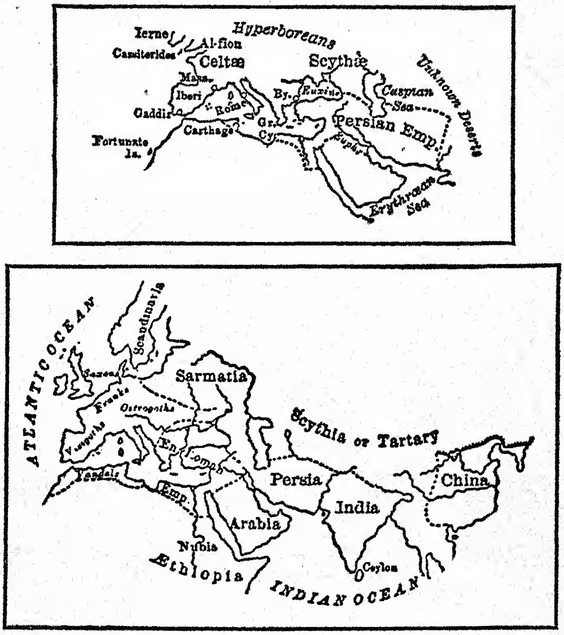
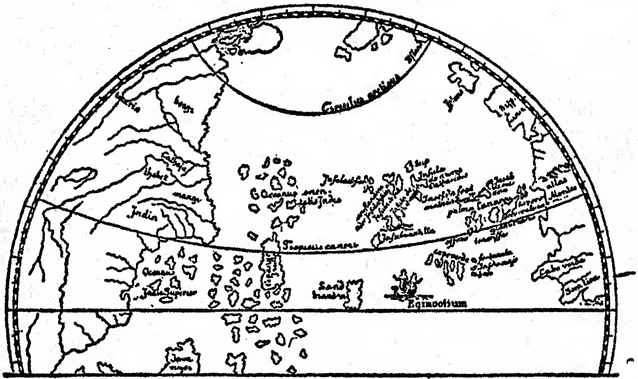


Fig. 5 —Geographical Knowledge Before Atlantic Exploration.
Upper map, 500 B.C.; lower, 500 A.D.

murder and had settled in Iceland, was in his turn outlawed thence in 983; he sailed to the west and discovered a land which he called Greenland, because, as he said, "people will be attracted hither if the land has a good name." He returned to Iceland, and in the year 985 a large

number of ships—according to some authorities, thirty-five—followed him to the new settlement and established themselves on its southwestern shore.

In 986 Bjarni Herjulfson-Bjarni, the son of Herjulf, in a voyage from Iceland to Greenland, was driven a long distance from the accustomed track. Various data furnished by this narrative, in the original Iceland records, have enabled geographers to determine the various coasts dimly seen by Bjarni, but upon which he did not land. They are supposed to have been those of Long Island,



The Ocean and Islands between Western Europe and Eastern Asia from the Globus of Martin Behaim 1492.

Fig. 6 —Map Showing Coast of America When It was Believed to Be China and India.

Rhode Island, Massachusetts, Nova Scotia and Newfoundland.

In the year 994 Leif Erikson—Leif the son of Erik the outlaw—bought Bjarni's ship and engaged thirty-five men to navigate it, as he intended to sail upon a voyage of discovery. He asked his father, Erik, to be the captain; but

Erik declined, being, as he said, well stricken in years. They sailed away into the sea and discovered first the land

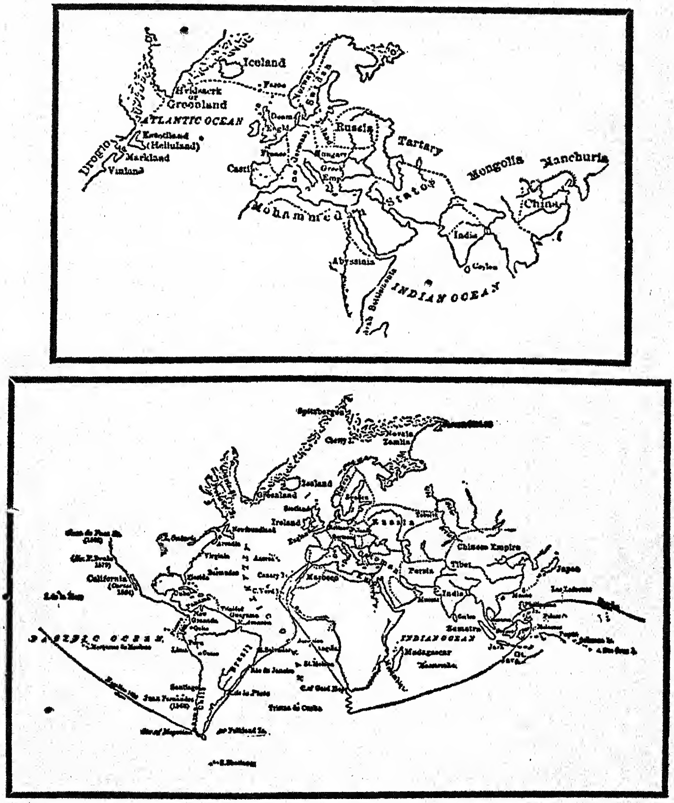


Fig. 7 —Extent of Geographical Knowledge at First Atlantic and First Pacific Exploration. 1000 A.D.; 1500 A.D.

which Bjarni had discovered last. They went ashore, saw no grass, but plenty of icebergs and an abundance of

flat stones. From the latter circumstance they named the place Helluland, hellu signifying a flat stone. There can be no doubt that the spot thus named is the modern Newfoundland. They went on board again and proceeded on their way. They went ashore a second time where the land was flat and covered with wood and white sand. "This," said Leif, "shall be named after its qualities and called Markland" (woodland). Again embarking and sailing to the south, they reached 'Vinland,' so called because of the wild grapes. This was probably the first recorded landing on the eastern shore of what is now the United States.

Thus beginning from a fearful restraint of venturing upon the sea, the ancients first explored the Mediterranean, then, growing bolder, ventured beyond the Straits of Gibraltar and crept along the African coast and up toward the north of Europe. The perils of the open ocean were first dared by the Norsemen, to whom is due the honor of having first landed upon and truly discovered the continent of America, an honor furthered by Columbus, Amerigo Vespucci and later navigators.

The next great event was the doubling of the Cape of Good Hope by Bartholomew Diaz in 1486. He had indeed doubled it without knowing it, for having taken a wide sweep to sea after a long southern voyage, on again making for the land he could find none; only on turning to a more northerly course did he see land one hundred miles to the eastward of the formidable cape which never before had been passed.

It avails little to tell the voyage of Columbus and his discovery of the West Indies in 1492 or of the curious circumstances which led to the use of Amerigo's name. The Florentines were eager to have Amerigo's work recognised, and when a Frenchman of St. Dié republished his narrative, making an error in the date which made it seem that Amerigo preceded Columbus, Florence took it up and Spain made no protest in favor of Columbus, whom she

had allowed to die in penury and disgrace. Sebastian Cabot, a true navigator, discovered Hudson's Bay in 1518.

Vasco de Gama in 1497 followed the track of Bartholomew Diaz and reached India by doubling the Cape of Good Hope. It did not occur to him, however, to continue his journey, and in returning to Portugal he retraced his path. In 1519 Ferdinand Magellan found the straits between the Atlantic and the Pacific which are known as the Magellan Straits to this day, and one of the vessels of his expedition was the first to circle the earth.

With the circumnavigation of the globe and the opening of all oceans to daring navigators, nautical exploration practically ceased. Since that time numberless geodetic surveys have been made. These form the modern counterpart of the quests of the sailors of olden time. Instead of vaguely determining the positions of continents the modern maritime surveyor determines the precise positions of minor points on the shores of mainlands or islands, and charts the submerged reefs.

With the Challenger expedition sent out by the British government in 1872, a new kind of exploration was born. This was the exploring of the ocean bed, the discovery of mountains and valleys, "shallows" and "deeps," beneath the ocean's surface. For, be it remembered, the bed of the ocean is almost as much carved as is the surface of the land. From the depth of the lowest deep to sea level is a greater mountain elevation than from the sea level to the summit of Mt. Everest.

This form of exploration has gone on continuously, each succeeding decade adding to the knowledge of the sea bottom, and in this work the American navy has taken a leading place. The greatest ocean depth yet charted was found in 1912 off the north coast of Mindanao, Philippine Islands, a depth of 32,078 feet being recorded. This is 2,907 feet greater than the height of the highest peak of the Himalayas.

One of the most important submarine explorations of

recent years was reported in 1913, when Sir Douglas Mawson produced evidence of the remains of a continent stretching from Tasmania to Antarctica. Although the shallowest water over this submerged continent is 545 fathoms, or over 3,270 feet, the ridge—which is 150 miles long—rises at least 11,000 feet above the ocean floor. This discovery has been of incalculable importance in explaining certain similarities of animal life in Tasmania, Australia, and South America.

Exploration in its more familiar meaning has recently been directed to Polar search, and the Twentieth Century will forever stand out memorable in the annals of human history, since both the North and South Poles have been reached. Not until one fully realizes for how many centuries indefatigable and heroic seekers have essayed this perilous adventure, not until one reckons the awful toll of life, does the sheer splendor of the work of Commander Peary, Captain Amundsen and Captain Scott stand out in its true colors.

In the reign of Henry VIII, Doctor Robert Thorne declared that "if he had facultie to his will, the first thing he would understande, even to attempt, would be if our seas northwards are navigeable to the Pole or no." Accordingly "two faire ships" set forth in May, 1527. One of these vessels was wrecked off Newfoundland and there is no record that the other ever returned. A similar fate met Sir Hugh Willoughby, who sailed in 1563. He lost one vessel on "the Muscovy coast" and, with all his companions, perished miserably in Lapland.

Martin Frobisher, the great navigator, was not able to reach further north than 63°, but in 1585 Captain John Davis reached lat. 80° and on his third voyage he reached even further, sighting land which he named Cape Sanderson, a few minutes north of the point attained on his former voyage. Henry Hudson, the explorer of the Hudson River, in an attempt to reach the Pacific Ocean by the long sought North West passage, in 1607 attained the lat-

itude of 81°. The last of the early explorers was William Baffin, who in 1615 sailed around Greenland, giving his name to Baffin's Bay.

The nineteenth century was remarkable for strenuous endeavor. In 1818 Sir John Parry overtopped all earlier efforts and reached as far north as 82°. The hopes of the world, however, rose high when, in the spring of 1845, Sir John Franklin sailed for polar waters. The silence of the Arctic winter fell over the expedition, and rescue parties later found the bodies of Franklin and his men, who had died in forwarding their quest. Scarcely less tragic was the loss of the American De Long expedition in 1881.

The great figure in Polar work during the nineteenth century unquestionably was Commander Robt. E. Peary, who in 1886 first attacked the Arctic terrors. His first expedition was to Greenland, and from that time he has been almost constantly in the Arctic region under the auspices of several learned and scientific societies. But in spite of his indefatigable efforts, a Norwegian, Dr. Nansen, carried off the banner for the highest point reached in the nineteenth century. He built a vessel—the *Fram*—to withstand ice pressure and trusted that the currents would carry him to the Pole. He reached latitude 86° 14′, and brought back a mass of extremely useful scientific information.

An attempt to reach the North Pole by balloon was made by Prof. Andre in 1897. The expedition was never heard from, for aero-navigation had not then made the wonderful advances compassed in the first two decades of the twentieth century.

The last year of the century saw the northern mark again pushed forward. An expedition under the command of the Duke of the Abruzzi sailed in 1899. Dr. Nansen's furthest point was passed, and a dash was being made for the Pole when the leader of the expedition was severely frostbitten, and he accordingly transferred the

perilous command to Capt. Cagni, who reached the point of latitude 86° 34′.

Two succeeding important Arctic expeditions may be mentioned: the Ziegler expedition commanded by Anthony Fiala in 1903 and that of Capt. Amundsen. Fiala spent two years above the 81st parallel, and added greatly to polar knowledge; and Amundsen achieved the North West passage—which had baffled the world for centuries—in his tiny ship the *Gjoa*.

It was on April 6, 1909, that Commander Robert E. Peary, U.S.N., brought himself imperishable fame by the conquest for the North Pole. The triumph was accentuated by the fact that (except for the last dash for the Pole) Commander Peary was accompanied by a scientific staff of considerable eminence and that the results of his exploration were as profitable in scientific value as they were thrilling in their daring.

Leaving Etah on August 17, 1908, the *Roosevelt* reached Cape Sheridan, on the shore of the Arctic Sea, on September 1. There Peary established a winter camp. Throughout the winter, sledging parties carried loads of provisions to a northern camp at Cape Columbia, and on February 15, 1909, the first of the five detachments of the North Pole sledge party left Cape Sheridan. The distance from Cape Columbia—the last mainland point—was 475 miles.

As Peary advanced, one after another of the supporting parties were returned to their base, and, when the North Pole was but 140 miles distant, preparations were made for the final dash. Only five men participated in the final burst of speed, Commander Peary, Matt Hensen (his colored servant) and three Eskimos. The distance was covered in five forced marches of forty hours, and the Pole was reached before noon on April 6, 1909. Thirty hours were spent in taking observations under a cloudless sky and with a temperature not exceedingly cold. The lowest temperature recorded during this time was —30° Fahr.

The ice at the Pole was described as "chalky white" and practically level.

At the North Pole there is no land. The soundings made by Commander Peary, five miles from the Pole, gave a depth of 1,500 fathoms without touching bottom. As Nansen discovered a deep oceanic basin in Asian Arctic waters, the existence of an Arctic continent of any considerable size is disproved.

Shortly before the news arrived of Commander Peary's success, Dr. Frederick A. Cook made the claim of having attained the North Pole on April 21, 1908. Until competent evidence disproved his assertions, Dr. Cook secured wide publicity and some notoriety. Official investigation showed that the Eskimos who were supposed to have accompanied Dr. Cook to the Pole had wintered with him in Jones Sound, and they asserted that he had not gone north at all. His supposed observations of latitudes and longitudes, it was shown, had been forged for him by a mathematician in Europe. The supposed scientific data he sent to the University of Copenhagen were declared by that body to be self-contradictory. His name was publicly stricken from the records of many organizations which had yielded credence to his first unexamined report.

Further interest in the Arctic has been divided between the Stefansson and Crocker Land expeditions, both for the purpose of determining the geographical boundaries of unmapped portions of land in the Arctic Ocean. Stefansson's work as an ethnologist has resulted in the acquisition of a vast body of knowledge concerning the natives of regions never before visited by white man. In November, 1915, Stefansson sailed again for the North with a well equipped scientific corps. He took provisions for two or even three years and a hundred and sixty dogs.

In scientific observations the Crocker Land expedition has been fruitful. It sailed on July 2, 1913, from Broolyn on the steam whaler *Diana* for Smith Sound. It was in charge of Donald B. Mac Millan, an ethnologist of note,

with a staff of scientists on board to help him with the observations. It was planned that the expedition establish winter quarters on Ellesmere Island and start eastward for the supposed Crocker Land in February, 1914. Peary gave this name to land which he saw in the west during his survey of Grant Land in 1906. It was the purpose of Mac Millan to find if this land existed and then to explore it.

In 1914, after a long journey, Mac Millan reported that the Crocker Land had disappeared from the charts of the Polar Ocean, due to geographical inaccuracies, frequent in polar exploration. Mac Millan and Ensign Green in March, 1914, started on a perilous journey across the floes of the Arctic Ocean, in a quest for the land, but although they reached a point in the neighborhood of 82° 30′ N. latitude, 102° W. longitude, where Peary had charted the land, it was not seen. Most of the dogs were lost, and the two explorers reached land only barely in time to save their own lives, for the next day the polar pack was entirely disrupted. Their soundings and collections promise to be of great interest, and the biological and geological material gathered by the party is most valuable.

The history of Antarctic exploration begins in 1769, when Captain James Cook, the great English navigator of the eighteenth century, discovered that New Zealand was an island. In 1773, Captain Cook sailed to the south again and reached latitude 71°. The next great name in South Polar exploration was Sir James Ross, who discovered the active volume of Mt. Erebus and its twin peak Mt. Terror in latitude 77°. The next southing was reached by Captain Borchgrevink in 1889, who attained latitude 78°, and the following year located the South Magnetic Pole in latitude 73°. In 1903, Captain Scott reached latitude 82°.

One of the finest sledging exploits on record was that of Lieutenant Shackleton, who, on January 9, 1909,

reached within 111 miles of the South Pole, but was compelled to return because of the impassable character of the lofty land masses and by insufficiency of rations. While Lieutenant (afterwards Sir Ernest) Shackleton did not discover the South Pole, the honor of having discovered the continent of Antarctica undoubtedly should be assigned to him.

On December 16, 1911, Captain Roald Amundsen reached the South Pole. Disregarding Sir Ernest Shackleton's experience with Manchurian ponies, Amundsen depended entirely upon skiis and Eskimo dogs. He wintered as far south as 81°, and spent a large part of the winter ensuring against any members of the expedition becoming lost. On October 20, the southern march was begun, the party numbering only five men. The conditions of travel at first were severe, as the road he took to the South Pole was over the peaks of South Victoria Land. Once the lofty plateau was attained, however, travel was easy, and Amundsen remained satisfied with short marches, the average advance daily being only about 17 miles.

At the South Pole Amundsen remained 24 hours and took a complete series of observations. A small tent which the explorer had brought with him was erected at the Pole, and the Norwegian flag was left flying above it.

Saddest among all the splendid exploits with which Polar research has been adorned was the achievement of the South Pole by Captain R. F. Scott, thirty-five days after Amundsen's discovery, and the British explorer's death on his return to his base of supplies. He was within eleven miles of safety when a blizzard overtook the party, and a camp was made in the snow. There was then enough fuel for one hot meal and food enough for four meals. But the blizzard showed no signs of cessation. Captain Oates, one of the members of the party, feeling that there was a greater chance for Captain Scott's return if there were fewer mouths to feed, de-

liberately walked out into the blizzard and perished. The sacrifice was in vain, for six months afterwards a rescue party found the bodies of Captain Scott and his companions, together with a complete diary giving a detailed acount of his trip, of his discovery of the Pole and the records; and until his fingers began to stiffen in death, every incident of the fatal return journey was faithfully and touchingly set down.

While land exploration now deals mainly with the topography of little known regions and is carried on by the governments of the world, it is not without its dangers. Mr. Noel Williamson, in 1910, while engaged in mapping the Assam-Thibet borderland, was massacred with two hundred of his natives. Dr. Sven Hedin, however, has succeeded in exploring the whole of Western Thibet and has certified the modern knowledge of Central Asia. It was in 1908 that he completed this exploration, during which he made a complete survey of the main topographical features of the whole of western Tibet. He discovered a part of the Trans-Himalaya Range and the main upper branch of the Indus River. It took three years to complete the work, and it is therefore possible now to construct a map of that hitherto unknown region.

The most important exploratory work, now being done year by year, is the work of boundary commissions. Thus the demarcation of the Alaskan-Canadian boundary from Mt. St. Elias northward to the Arctic Ocean along the 141st meridian of west longitude, was completed in 1915. The regions were of extreme ruggedness and were deemed almost inaccessible. In the Nigeria-Kamerun boundary commission's work, three new pigmy tribes were found. An effort to explore the unknown desert of Arabia was prevented by hostile tribes, though Captain Leachman was successful in making his way from Damascus to Ojair on the Persian Gulf through Central Arabia. Another new group of dwarfs was found in 1914 by an expedition under Kingdon Ward on the Chungtien plateau. Dr. and

Mrs. Workman have disclosed vast unknown portions of the Himalayas and in 1913 discovered the Siachen glacier system, the largest in the world.

Dr. M. A. Stein added to the study of Central Asia by mapping 17,000 square miles of mountain land in the Chinese province of Kansu and along the eastern border of East Turkestan. He found many ruins of ancient towns, and it took fifty camels to transfer his vast collections of historic relics.

British and French expeditions have mapped the dark continent of Africa, and even the deserts of Central Australia have been crossed by many surveys. Colonel Theodore Roosevelt's hunting expedition, which returned in 1910, added greatly to the knowledge of fauna and flora of Africa. About 11,000 specimens were brought to the United States National Museum. In South America also the most notable expedition was made by a party headed by Colonel Theodore Roosevelt, resulting in the navigation of a river—now called by the Brazilian government Rio Teodoro—a large section of which had never been visited. It proved to be a tributary of the Madeira, which in its turn is a southern tributary of the Amazon. Although very tortuous, the general course of the Rio Teodoro is due north, through a rugged, densely wooded country, uninhabited by man and almost devoid of beast. The voyage involved a journey of 750 kilometres and lasted two months, from February to April, 1914. The scarcity of game, limited food and fever conditions added to the difficulties of the undertaking. Thirty unnavigable rapids made the voyage both exhausting and dangerous.

Since the conquest of the poles has been achieved, since the interiors of the great continents have been forced to yield up their secrets, since the abysmal depths of the ocean are charted, exploration has taken to itself wings. In America, as in Europe, great activity is being manifested in the preparation of aeronautical maps,

charts which reveal the direction of air currents as nautical charts reveal those of ocean currents. Dangerous vortices or air-whirls are to be marked upon these maps like reefs upon the ocean. These maps include an area of one degree each of latitude and longitude. Railways, rivers and canals are also shown by suitable colors and symbols. Objects of special form or prominence, such as heights, buildings and aerodromes are clearly indicated. With the advance in meteorological science and aviation mechanics, it is expected that flight through the air may be as safely protected as travel on the sea.

CHAPTER III

GEOLOGY IN THE DARK AGES

THE decline of the Roman Empire, while, as has been seen, it did not prevent the growth of the adventurous spirit, was a sore blow to scientific study. Life became too insecure to permit leisure, and the governmental situation was uncertain in all countries.

From the middle of the eighth century onward for some five hundred years the Arabs alone kept alive the feeble flame of interest in researches into the secrets of Nature. With great labor and at large cost they procured as much as they could obtain of the literature of Ancient Greece and Rome and studied and translated into their own language the works of the best writers in philosophy, medicine, mathematics and astronomy. They were thus able to some extent to enlarge the domain of these subjects. But Geology was a subject to which the students of the Caliphates never took kindly.

Albert the Great (1205-1280 A.D.), the most learned man of his time, mentions that a branch of a tree was found on which was a bird's nest containing birds, the whole being solid stone. He acounted for this strange phenomenon by the "vis formativa" of Aristotle, an occult force, which, according to the prevalent notions of the time, was capable of forming most of the extraordinary objects discovered in the earth.

One of the keenest observers whose opinions have been recorded was the illustrious painter, architect, sculptor and

engineer, Leonardo da Vinci (1452-1519). His attention having been aroused by the abundantly fossiliferous nature of some of the rocks in northern Italy, in which canals were cut, he concluded that the shells contained in these rocks had once been living creatures on the sea-floor and had been buried in the silt washed off the land. He ridiculed the notion that they could have been produced by the influence of the stars, and he asked where such an influence could be shown to be at work now. But he pointed out that besides the shells, there were at various heights terraces of gravel composed of materials that had evidently been rounded and accumulated by moving water.

Fracastoro, in the year 1517, gave clear expression to his convictions about fossils, which were in accordance with those of Leonardo da Vinci. During the building of the citadel of San Felice in Verona, the workers found fossil mussels in the rocks and laid them before Fracastoro, begging him to explain the marvel. Fracastora repudiated the doctrine of a "vis plastica" in the earth as impossible, and just as little did he give credence to the view that explained fossils as creatures left by the great Flood. There was left, he continued, only one possible explanation—that the fossils were the remains of animals which had once lived in the localities where their remains are now imbedded.

Far more illustrious than the majority of his contemporaries in science was George Bauer, better known by his "nom de plume" of Agricola. Werner calls him the father of metallurgy and the originator of the critical study of minerals. Agricola's observations on crystalline form, cleavage, hardness, weight, color, luster, etc., have served as a model for all subsequent descriptions of minerals. On the other hand, Agricola's remarks about fossils are of much less value. He had devoted little attention to the fossil remains of animals and plants, and he unfortunately united under the name "Fossilia" both minerals and petrified organisms. This use of the term "Fossils"

was perpetuated for two centuries in the literature, having been more especially adopted by the famous Wernerian school.

Giulio Cardano (1552) pointed to fossil shells as certain evidence that the sea once covered the sites of the hills. The skilful anatomist, Gabriel Falloppio (d. 1562), when he met with the bones of elephants, teeth of sharks, shells and other fossils, refused to admit them to be anything but earthy concretions, because he deemed that to be a simpler solution of the problem than to suppose that the waters of the Deluge could have reached as far as Italy.

It is astonishing to find how tenaciously, until the middle of the eighteenth century, so many authors clung to most absurd ideas, even altho the fossils were being made known by means of good illustrations to an ever-increasing number of observers. The works of Aldrovandi, Athanasius, Kircher the Jesuit, Sebastian Kirchmaier, Alberti, Balbini, Geyer, Hartley and many others in the seventeenth century contain good figures and extended the knowledge of the fossils found in various European localities. The fossils were, however, treated usually as mineral curiosities or as illusions of nature, sometimes as forms called forth in the earth by "vis plastica" or some other force, sometimes compared with living mussels, snails, sea-urchins and plants, and named accordingly.

In the crowd of writers who took part in the long geological controversy by far the most illustrious was Nicolas Steno (1631-1687). Born and educated in Copenhagen, he traveled to Leyden, Paris and Austria and eventually settled in Florence as physician to the Grand Duke Ferdinand the Second.

In 1669 there appeared in Florence his treatise, "De Solido intra soliaum naturaliter contento," which must be regarded as one of the landmarks in the history of geological investigation. In this he says that the strata of the earth are such as would be laid down in the form

of sediment from turbid water. The objects enclosed in them, which in every respect resemble plants and animals, were produced exactly in the same way as living plants and animals are produced now. Where any bed encloses either fragments of another and therefore older bed or the remains of plants or animals, it cannot be as old as the time of the Creation. If any marine production is found in any of these strata, it proves that at one time the sea has been present there, while if the remains are those of terrestrial plants or animals, the sediment must have been laid down on land by some river or torrent.

Another notable Italian writer, Anton-Lazarro Moro, appeared in the first half of the eighteenth century. He discussed the possibility of explaining the position of fossil shells in the mountains by reference to the Noachian Deluge and dismissed this supposition as untenable. After giving an account of the uprise of a new volcanic island in the Greek Archipelago in the year 1707, of the appearance of Monte Nuovo near Naples in 1538 and of the recorded eruptions of Vesuvius and Etna, and starting with the proposition that the fossil shells are really productions of the sea, he proceeds to unfold his theory that the position of these shells, and the origin of the rocks that enclose them, are to be assigned to the operation of volcanic action.

The following semi-tragic, semi-comic event was a decided setback to the prevailing belief in the theory of the direct origin of fossils—*i.e.*, that they were imitations produced in the rocks by some unknown causes: Johannes Bartholomew Beringer, a professor in the University of Wurzburg, published in 1726 a paleontological work entitled "Lithographia Wurceburgensis." In it a number of true fossils were illustrated, belonging to the Muschelkalk or Middle Trias of North Bavaria, and beside these were more or less remarkable forms, even sun, moon, stars and Hebraic letters, said to be fossils, and described and illustrated as such by the professor. As a matter of

fact, his students, who no longer believed in the Greek myth of self-generation in the rocks, had placed artificially concocted forms in the earth, and during excursions had inveigled the credulous professor to those particular spots and discovered them! But when at last Beringer's own name was found apparently in fossil form in the rocks, the mystery was revealed to the unfortunate professor. He tried to buy up and destroy his published work, but in 1767 a new edition of the work was published, and the book is preserved as a scientific curiosity. Many of the false fossils (Lugensteine) may be seen in the mineral collections at Bamberg.

Palissy, a French writer on "The Origin of Springs from Rain-water" and of other scientific works, undertook in 1580 to combat the notions of many of his contemporaries in Italy that petrified shells had all been deposited by the Universal Deluge. "He was the first," said Fontenelle when, in the French Academy, he pronounced his eulogy, nearly a century and a half later, "who dared assert in Paris that fossil remains of testacea and fish had once belonged to marine animals." Palissy's ideas were violently attacked by his compatriots, and he was denounced as a heretic.

Next among the notable workers was the versatile B. F. Guettard, who traveled through France, England, Germany and Poland, and whose great desire it was to reproduce his scientific observations on maps. Guettard described the processes of land denudation effected by the solvent and destructive agency of rain and rivers and by the abrasion of the waves. This is probably the first paper in which a systematic account of denudation is given in its relation to changes in the configuration of the earth's surface. The most brilliant of Guettard's achievements was his discovery of the volcanic rocks in the Auvergne region.

Toward the close of the eighteenth century the idea of distinguishing the mineral masses on our globe into sep-

arate groups and studying their relations began to be generally diffused. Of these investigators, Pallas and de Saussure were among the most celebrated whose labors contributed to this end. After an attentive examination of the two great mountain chains of Siberia, Pallas announced the result that the granite rocks were in the middle, the schistose at their sides and the limestones again on the outside of these; and this he conceived would prove a general law in the formation of all chains composed chiefly of primary rocks.

In his "Travels in Russia," in 1793 and 1794, he made many geological observations on the recent strata near the Volga and the Caspian and adduced proofs of the greater extent of the latter sea at no distant era in the earth's history. His memoir on the fossil bones of Siberia attracted attention to some of the most remarkable phenomena of Geology. He stated that he had found a rhinoceros entire in the frozen soil, with its skin and flesh. An elephant found afterward in a mass of ice on the shore of the North Sea removed all doubts as to the accuracy of such a remarkable discovery. Quirini, in 1676, was the first writer who ventured to maintain that the universality of the Noachian cataclysm ought not to be insisted upon.

The great mathematician Leibnitz published his "Protogoea" in 1680. He imagined this planet to have been originally a burning luminous mass, which ever since its creation has been undergoing refrigeration. When the outer crust had cooled down sufficiently to allow the vapors to be condensed they fell and formed a universal ocean, covering the loftiest mountains and investing the whole globe. The crust, as it consolidated from a state of fusion, assumed a vesicular and cavernous structure, and being rent in some places, allowed the water to rush into the subterranean hollows, whereby the level of the prieval ocean was lowered. The breaking in of these vast caverns is supposed to have given rise to the dislocated and deranged position of the strata, "which Steno had de-

scribed," and the same disruptions communicated violent movements to the incumbent waters, whence great inundations ensued. The waters, after they had been thus agitated, deposited their sedimentary matter during intervals of quiescence, and hence the various stony and earthy strata.

Robert Hooke (1635-1703) was one of the most brilliant, ingenious and verstile intellects of the seventeenth century. Among the many subjects to which he directed his attention and on which his remarkable powers of acute observation and sagacious reflection enabled him to cast light, some of the more important problems of Geology must be numbered. In 1705 appeared the "Posthumous Works of Robert Hooke, M.D.," which contained a "Discourse on Earthquakes."

He accounts for the shells found in mountains by saying that such things may be due to the action of earthquakes, "which have turned plains into mountains and mountains into plains, seas into land and land into seas, made rivers where there were none before and swallowed up others that formerly were, and which, since the creation of the world, have brought many great changes on the superficial parts of the earth and have been the instruments of placing shells, bones, plants, fishes and the like in those places where, with much astonishment, we find them."

About 1690 appeared Thomas Burnet's "Theory of the Earth." The title is characteristic of the age, "The Sacred Theory of the Earth, containing an Account of the Original of the Earth and of all the general Changes which it hath already undergone, or is to undergo, till the Consummation of all Things." Even Milton had scarcely ventured in his poem to indulge his imagination so freely in painting scenes of the Creation and Deluge, Paradise and Chaos. He explained why the primeval earth enjoyed a perpetual spring before the flood, showed how the crust of the globe was fissured by "the sun's

rafs," so that it burst, and thus the diluvial waters were let loose from a supposed central abyss.

The celebrated naturalist, John Ray (1627-1705), participated in the same desire to explain geological phenomena by reference to causes less hypothetical than those usually resorted to. In his essay on "Chaos and Creation" he proposed a system, agreeing in its outline and in many of its details with that of Hooke, but his knowledge of natural history enabled him to elucidate the subject with various original observations. Earthquakes, he suggested, might have been the second causes employed at the Creation in separating the land from the waters and in gathering the waters together into one place.

Among the contemporaries of Hooke and Ray, John Woodward (1665-1722), a professor of medicine, had acquired the most extensive information respecting the geological structure of the crust of the earth. His systematic collection of specimens, bequeathed to the University of Cambridge and still preserved there as arranged by him, shows how far he had advanced in ascertaining the order of superposition. He conceived "the whole terrestrial globe to have been taken to pieces and dissolved at the flood and the strata to have settled down from this promiscuous mass as any earthy sediments from a fluid." Ray immediately, by the undeniable evidences adduced from fossil deposits, disproved the unfounded nature of this assertion.

An illustrious observer in the geological domain appeared in Antonio Vallisneri (1661-1730), professor of medicine in Padua. In the course of his journeys he had opportunities of seeing much of the geology of his native country and of forming a clearer conception of the fossiliferous formations of the great central mountain-chain than any one had done before him. His works were rich in original observations.

He attempted the first general sketch of the marine deposits of Italy, their geographical extents and most

characteristic organic remains. In his treatise "On the Origin of Springs," he explained their dependence on the order and often on the dislocations of the strata and reasoned philosophically against the opinions of those who regarded the disordered state of the earth's crust as exhibiting signs of the wrath of God for the sins of man.

Altho reluctant to generalize on the rich materials accumulated in his travels, Vallisneri had been so much struck with the remarkable continuity of the more recent marine strata, from one end of Italy to the other, that he came to the conclusion that the ocean formerly extended over the whole earth, and after abiding there for a long time, had gradually subsided.

The last and not the least of the cosmogonists was G. L. Leclerc de Buffon (1707-1788), one of the greatest pioneers, who figured so conspicuously in the history of France. At first interested in Physics and Mathematics, he gradually broadened his field of observation, taking in the whole realm of Nature. He adopted the theory of an original volcanic nucleus, together with the universal ocean of Leibnitz. By this aqueous envelope the highest mountains were once covered. Marine currents then acted violently and formed horizontal strata by washing away solid matter in some parts and depositing it in others; they also excavated deep submarine valleys. The level of the ocean was then depressed by the entrance of a part of its waters into subterranean caverns, and thus some land was left dry.

Soon after the publication of his "Natural History," in which was included his "Theory of the Earth," he received an official letter (dated January, 1751) from the Sorbonne, or Faculty of Theology in Paris, informing him that fourteen propositions in his works "were reprehensible and contrary to the creed of the Church." The first of these obnoxious passages, and the only one relating to geology, was as follows: "The waters of the sea have produced the mountains and valleys of the land; the waters of the

heavens reducing all to a level, will at last deliver the whole land over to the sea, and the sea, successively prevailing over the land, will leave dry new continents like those which we inhabit."

Buffon was invited by the college in courteous terms to send in an explanation, or rather a recantation, of his unorthodox opinions. To this he submitted, and a general assembly of the faculty having approved of his "Declaration," he was required to publish it in his next work.

The grand principle which Buffon was called upon to renounce was simply this: "That the present mountains and valleys of the earth were due to secondary causes, and that the same causes will in time destroy all the continents, hills and valleys and reproduce others like them." Now, whatever may be the defects of many of his views, it is no longer controverted that the present continents are of secondary origin. The doctrine is as firmly established as the earth's rotation on its axis, and that the land now elevated above the level of the sea will not endure forever is an opinion which gains ground daily in proportion as experience of the changes now in progress is enlarged.

Tagioni (1751) opposed Buffon in his theory regarding the origin of valleys. Buffon attributed them principally to submarine currents, while the Tuscan naturalist labored to show that both the larger and smaller valleys of the Apennines were excavated by rivers and floods, caused by the bursting of the barriers of lakes after the retreat of the ocean. He was a contemporary of Werner, who ushers in a new era.

CHAPTER IV

LAYING THE ROCKS BARE

WITH the freeing of geological study from the bondage of the Middle Ages, there came a new enthusiasm and a determined spirit to discountenance speculation and to seek untiringly in the field and in the laboratories after new observations, new truths. Interest was directed, in the first place, toward the investigation and description of the accessible parts of the earth's crust. The composition and arrangement of the strata were studied with enthusiasm. The bolder inquirers ventured into wild recesses of mountain-chains and climby snowy peaks, whose difficulties had hitherto been thought insurmountable; travelers explored the uninhabited plains of Siberia, the remote mountain-ranges of Asia and America and brought home with them new scientific material and observations of the highest importance for comparative research. Scientific research supplanted misty supposition.

Together with this arose the realization of the value of understanding the works of the geologists of the past. For the first time a History of Geology became possible. As Sir Archibald Geikie said: "In no department of natural knowledge is the adoption of this historical method more necessary and useful than it is in Geology. The subjects with which that branch of science deals are, for the most part, not susceptible of mathematical treatment. The conclusions formed in regard to them, being often necessarily incapable of rigid demonstration, must rest on a

balance of probabilities. There is thus room for some difference of opinion both as to facts and the interpretation of them. Deductions and inferences which are generally accepted in one age may be rejected in the next. This element of uncertainty has tended to encourage speculation. Moreover, the subjects of investigation are themselves often calculated powerfully to excite the imagination.

"The story of this earth since it became a habitable globe, the evolution of its continents, the birth and degradation of its mountains, the marvelous procession of plants and animals which, since the beginning of time, has passed over its surface—these and a thousand cognate themes with which Geology deals, have attracted numbers of readers and workers to its pale, have kindled much general interest and awakened not a little enthusiasm. But the records from which the chronicle of events must be compiled are sadly deficient and fragmentary. The deductions which they suggest ought frequently to be held in suspense from want of evidence. Yet with a certain class of minds fancy comes in to supply the place of facts that fail. And thus Geology has been encumbered with many hypotheses and theories which, plausible as they might seem at the time of their promulgation, have one by one been dissipated before the advance of fuller and more accurate knowledge. Yet before their overthrow it may often be hard to separate the actual ascertained core of fact within them from the mass of erroneous interpretation and unfounded inference that forms most of their substance."

The Modern Period begins with the advent of a man who bulks far more largely in the history of Geology than any of those with whom up to the present we have been concerned—a man who wielded an enormous authority over the mineralogy and geology of his day. Through the loyal devotion of his pupils, he was elevated even in his lifetime into the position of a kind of scientific pope, whose decisions were final on any subject regarding which

he chose to pronounce them. During the last quarter of the eighteenth century by far the most notable figure in the ranks of those who cultivated the study of minerals and rocks was unquestionably Abraham Gottlob Werner (1749-1817). The vast influence which this man wielded arose mainly from his personal gifts and character and especially from the overmastering power he had of impressing his opinions upon the convictions of his hearers.

Werner was born in 1749 at Wehran, in Upper Lupatia, of a family which had long been interested in the iron industry. Thus from infancy he was in intimate contact with people interested in topics akin to Geology. He early became interested in mineralogy and his tendency in this direction was encouraged by his father. The latter desired his assistance in the smelting houses at Wehran, but the boy's ambition to devote himself to minerals had taken too deep root, and he decided to go to the Riding Academy at Freiburg. He was a most ardent student and all his spare moments were spent in neighboring mines. In 1771 he went to the University of Leipzig, where he prosecuted the study of law for two years, but eventually returned to his first love, mineralogy. When only 25 years of age he published a book on minerals, then a wonder of arrangement, largely as a result of which he was appointed to the post of professor of mineralogy in the School of Mines at Freiberg, where he had formerly studied.

His manner of discourse also was so attractive and stimulating that he riveted the attention of his pupils, incited them to pursue the studies that he loved and fired them with a desire to apply his methods. Ostensibly he had to teach mineralogy—a science which in ordinary hands can hardly be said to evoke enthusiasm. But Werner's mineralogy embraced the whole of Nature, the whole of human history, the whole interests and pursuits and tendencies of mankind. From a few pieces of stone, placed almost at random on the table before him he would

launch out into an exposition of the influence of minerals and rocks upon the geography and topography of the earth's surface. He would contrast the mountainous scenery of the granites and schists with the tamer landscapes of the sandstones and limestones. Tracing the limits of these contrasts of surface over the area of Europe, he would dwell on their influence upon the grouping and characteristics of the nations. He would connect, in this way, his specimens with the migration of races, the spread of languages, the progress of civilization. He would show how the development of the arts and industries of life had been guided by the distribution of minerals, how campaigns, battles and military strategy as a whole had been dependent on the same course. The artist, the politician, the historian, the physician, the warrior were all taught that a knowledge of mineralogy would help them to success in their several pursuits. It seemed as if the most efficient training for the affairs of life were obtainable only at the Mining School of Freiberg.

The first feature of his grasp, distinguishable in every part of his life and work, was his overmastering sense of orderliness and method. When Werner entered upon his mineralogical studies the science of minerals was an extraordinary chaos of detached observations and unconnected pieces of knowledge. But his very first essay began to put it into order, and by degrees he introduced into it a definite methodical treatment, doing for it very much what Linnaeus had done some years before for botany. Like that great naturalist, he had to invent a language to express with precision the characters which he wished to denote, so that mineralogists everywhere could recognise them. For this purpose he employed his mother tongue and devised a terminology which, tho artificial and cumbrous, was undoubtedly of great service for a time. Uncouth in German, it became almost barbarous when translated into other languages. What would the modern English-speaking student think of a teacher who taught him,

as definite characters, that a mineral could be distinguished as "hard or semi-hard," "soft or very soft," as "very cold, cold, pretty cold or rather cold," as "fortification-wise bent," as "indeterminate curved lamellar," as "common angulo-granular" or as "not particularly difficultly frangible"?

Werner arranged the external characters of minerals in so methodical a way that they could readily be applied in the practical determination of species. Yet strangely enough he neglected the most important of them all—that of crystalline form. From the individual minerals he proceeded to the consideration of their distribution and the character and origin of the different rocks in which they occur. To this branch of inquiry he gave the name of geognosy, or knowledge of the earth, and he defined it as the science which reveals in a methodical order the terrestrial globe as a whole and more particularly the layers of mineral matter whereof it consists, informing as to the position and relations of these layers to each other, and enabling the formation of some idea of their origin. The term geology had not yet come into use, nor would either Werner or any of his followers have adopted it as a synonym for the "geognosy" of the Freiberg school. They prided themselves on their close adherence to fact as opposed to theory. They boasted of the minuteness and precision of their master's system, and contrasted the positive results to which it led with what they regarded as the vague conclusions and unsupported or idle speculations of other writers. Werner arranged the crust of the earth into a series of "formations," which he labeled and described with the same precision that he applied to the minerals in his cabinet.

But never in the history of science did a stranger hallucination arise than that of Werner and his school when they supposed themselves to discard theory and build on a foundation of accurately ascertained fact. Never was a system devised in which theory was more rampant; theory,

too, unsupported by observation, and, as is now known, utterly erroneous.

One of the fundamental postulates of the Wernerian doctrines was the existence of what were termed universal formations. When he elaborated his system, Werner had never been out of Saxony and the immediately adjacent regions. His practical knowledge of the earth was, therefore, confined to what he could see there, and so little was then known of the geological structure of the globe as a whole that he could not add much to his acquaintance with the subject by reading what had been observed by others, tho there can be little doubt that he stood greatly indebted to Lehmann and Füchsel. With this slender stock of acquirement, he adopted the old idea that the whole globe had once been surrounded with an ocean of water, at least as deep as the mountains are high, and he believed that from this ocean there were deposited by chemical precipitation the solid rocks which now form most of the dry land. He taught that these original formations were universal, extending round the whole globe, tho not without interruption, and that they followed each other in a certain order.

Werner affirmed that the first formed rocks were entirely of chemical origin, and he called them Primitive, including in them granite, which was the oldest, gneiss, mica-slate, clay-slate, serpentine, basalt, porphyry, and concluding with syenite as the youngest. Succeeding these came what he afterward separated as the Transition Rocks, consisting chiefly of chemical productions (graywacke, graywacke-slate and limestone), but comprising the earliest mechanical depositions and indicating the gradual lowering of the level of the universal ocean. Still newer, and occupying, on the whole, lower positions, marking the continued retirement of the waters, were the Floetz Rocks, composed partly of chemical, but chiefly of mechanical sediments, and including sandstone, limestone, gypsum, rock-salt, coal, basalt, obsidian, porphyry and

other rocks. Latest of all came the Alluvial series, consisting of recent loams, clays, sands, gravels, sinters and peat.

This system was not put forward tentatively as a suggestion toward a better comprehension of the history of the earth. It was announced dogmatically as a body of ascertained truth about which there could be no further doubt or dispute. "In recapitulating the state of our present knowledge," Werner declares with his characteristic emphasis, "it is obvious that we know with certainty that the floetz and primitive mountains have been produced by a series of precipitations and depositions formed in succession from water which covered the globe. We are also certain that the fossils which constitute the beds and strata of mountains were dissolved in this universal water and were precipitated from it; consequently the metals and minerals found in primitive rocks and in the beds of floetz mountains were also contained in this universal solvent and were formed from it by precipitation.

"We are still further certain that at different periods different fossils have been formed from it, at one time earthy, at another metallic minerals, at a third time some other fossils. We know, too, from the position of these fossils, one above another, to determine with the utmost precision which are the oldest and which the newest precipitates. We are also convinced that the solid mass of our globe has been produced by a series of precipitations formed in succession (in the humid way); that the pressure of the materials thus accumulated was not the same throughout the whole; and that this difference of pressure and several other concurring causes have produced rents in the substance of the earth, chiefly in the most elevated parts of its surface. We are also persuaded that the precipitates taking place from the universal water must have entered into the open fissures which the water covered. We know, moreover, for certain that veins bear all the marks of fissures formed at different times; and, by the

causes which have been assigned for their formation, that the mass of veins is absolutely of the same nature as the beds and strata of mountains, and that the nature of the masses differs only according to the locality of the cavity where they occur. In fact, the solution contained in its great reservoir (that excavation which held the universal water) was necessarily subjected to a variety of motion, while that part of it which was confined to the fissures was undisturbed and deposited in a state of tranquillity its precipitate."

It would be difficult to cite from any other modern scientific treatise a series of consecutive sentences containing a larger number of dogmatic assertions, of which almost every one is contradicted by the most elementary facts of observation. The habit of confident affirmation seems to have blinded Werner to the palpable absurdity of some of his statements. For example, the theory of a universal, primeval ocean occupying an excavation that was so deep that it overtopped the highest mountains was superficially most ridiculous. If this ocean covered the entire globe, where was the excavation and how did this deep ocean disappear? It may be interesting to know how Werner explained this natural question, but none of his writings satisfactorily answer it. In one place he thinks it possible that "one of the celestial bodies which sometimes approach near to the earth may have been able to withdraw a portion of our atmosphere and of our ocean." But if once the waters were abstracted, how were they to be brought back again so as to cover all the hills on which his highest Floetz formations were deposited?

One might have thought that having disposed of the universal ocean, even in this rather peremptory fashion, the Wernerians would have been in no hurry to call it back again and set the same stupendous and inexplicable machinery once more going. But the exigencies of their theory left them no choice. Having determined, as an incontrovertible fact, that certain rocks had been deposited

as chemical precipitates in a definite order from a universal ocean, when these philosophers, as their knowledge of Nature increased, found that some of these so-called precipitates occurred out of their due sequence and at much higher altitudes than had been supposed, they were compelled to bring back the universal ocean and make it rise high over hills from which it had already receded. Not only had they to call up the vasty deep, but they had to endow it with rapid and even tumultuous movement as it swept upward over forest-clothed lands. Having raised it as high as their so-called Floetz formations extended, and having allowed its waters to settle and deposit precipitates of basalt and greenstone, they had to hurry it away again to the unknown regions where it still remains.

So early as 1768, before Werner had commenced his mineralogical studies, Raspe had truly characterized the basalts of Hesse as of igneous origin. Arduino had pointed out numerous varieties of trap-rock in the Vicentine as analogous to volcanic products and as distinctly referable to ancient submarine eruptions. Desmarest had, in company with Fortis, examined the Vicentine in 1766 and confirmed Arduino's views. In 1772 Banks, Solander and Troil compared the columnar basalt of Hecla with that of the Hebrides. Collini, in 1774, recognised the true nature of the igneous rocks on the Rhine between Andernach and Bonn. In 1775 Guettard visited the Vivarais and established the relation of basaltic currents to lavas. Lastly, in 1779, Faujas published his description of the volcanoes of the Vivarais and Velay and showed how the streams of basalt had poured out from craters which still remain in a perfect state.

Leopold von Buch (1774-1852) was the most illustrious of the geologists taught by Werner. He was born in the Castle of Stolpe in Pomerania, the son of a nobleman with considerable property. While still a boy he displayed a passionate love of scientific inquiry, and his fondness for chemical and physical mineralogical studies led him to

select the Mining Academy of Freiberg for his collegiate course. While there Alexander von Humboldt and Freiesleben were among his fellow students, and with them he formed close ties of friendship. He made his home for nearly three years (1790-1793) with Professor Werner, for whom he entertained the deepest sentiments of reverence and friendship, and these were in no way altered when, in after years, some of his opinions began to diverge from the teaching of Werner.

Von Buch examined the raised beaches and the terraces of Scandinavia and came to the conclusion that the Swedish coast was slowly rising above the level of the sea. In this he agreed with the opinion that had been formed by Playfair with regard to the raised beaches of Scotland. In 1809 Von Buch was chiefly engaged in mineralogical and geological researches in the Alps. Meanwhile great interest had been roused throughout Europe by the results of Von Humboldt's brilliant volcanic studies in Central and South America, and Von Buch determined to make a special study of some volcanic district.

Accompanied by the English botanist, Charles Smith, he visited the Canary Isles and in 1815 convinced himself that they had been the center of intense volcanic activity. In his famous monograph, "A Physical Description of the Canary Islands," published in 1825, he enunciated his hypothesis of upheaval craters and distinguished between "centers" and "bands" of volcanic action. In 1817 he traveled to Scotland and visited Staffa and the Giant's Causeway. When he again returned to the Alps he renounced the Wernerian doctrines of the origin of basalt and other volcanic rocks and ascribed the upheaval of the Alps to the intrusion of igneous rocks.

At the time when Werner was in the zenith of his fame, during those seventies and eighties of the eighteenth century when young geologists were flocking to hear the wisdom from the lips of the prophet of geognosy in Freiberg, a private gentleman, living quietly in Edinburgh, was

deliberating and writing a work on the earth's surface that will live forever in the annals of Geology as one of its noblest classics. His work and that of his contemporaries is ably reviewed by Karl von Zittell.

James Hutton (1726-1797), the author of the famous "Theory of the Earth," was the son of a merchant and received an excellent education at the High School and University of his native city. His strong bent for chemical science induced him to select medicine as a profession. He studied at Edinburgh, Paris and Leyden and took his degree at Leyden in 1749, but on his return to Scotland he did not follow out his profession. Having inherited an estate in Berwickshire from his father, he went to reside there and interested himself in agriculture and in chemical and geological pursuits.

From his early days he had always taken a delight in studying the surface forms and rocks of the earth's crust and had lost no opportunity of extending his geological knowledge during frequent journeys in Scotland, England, in northern France and the Netherlands. At last Hutton set himself to the work of shaping his ideas into a coherent, comprehensive form and in 1785 read his paper on the "Theory of the Earth" before the Royal Society of Edinburgh. The publication of the work attracted little favorable notice, partly due to the involved, unattractive style of writing; in larger measure, however, it was due to the fact that the learning of the schools had no part in Hutton's work. Hutton's thoughts had been borne in upon him direct from nature; for the best part of his life he had conned them, tossed them in his mind, tested them and sought repeated confirmation in nature before he had even begun to fix them in written words or cared to think of anything but his own enjoyment of them. Hutton's work was projected upon a plane half a century beyond the recognised geology of his own time. Hutton's audience of geologists had to grow up under other influences than polemical discussions between Neptunists and Plutonists

and had to learn from Hutton himself how to tap the fountain of science at its living source.

In 1793 a Dublin mineralogist, Kirwan, attacked Hutton's work, and the great Scotsman, now advanced in years, resolutely determined to revise his work and do his best by it. Valuable additions were made and the subject-matter brought under more skilful treatment. In 1795 the revised work appeared at Edinburgh in independent form and in two volumes. It was his last effort; he died two years later from an internal disease which had overshadowed the closing years of his life.

The original treatise of Hutton is divided into four parts. The first two parts discuss the origin of rocks. The earth is described as a firm body, enveloped in a mantle of water and atmosphere and which has been exposed during immeasurable periods of time to constant change in its surface conformation. The events of past geologic ages can be most satisfactorily predicted from a careful examination of present conditions and processes. The earth's crust, as far as it is open to investigation, is largely composed of sandstones, clays, pebble deposits and limestones that have accumulated on the bed of the ocean. The limestones represent the aggregated shells and remains of marine organisms, while the other deposits represent fragmental material transported from the continents. In addition to these sedimentary deposits of secondary origin there are primary rocks, such as granite and porphyry, which, as a rule, underlie the aqueous deposits. In earlier periods the earth presented the aspect of an immense ocean, surmounted here and there by islands and continents of primary rock. There must have been some powerful agency that converted the loose deposits into solid rock and elevated the consolidated sediments above the level of the sea to form new islands and continents.

According to Hutton, this agency could only have been heat; it could not have been water, since the cement material (quartz, felspar, fluorine, etc.) of many sedimen-

tary rocks is not readily soluble in water and could scarcely have been provided by water. On the other hand, most solid rocks are intermingled with silicious, bituminous or other material which may be melted under the influence of heat. This suggested to Hutton his theory that at a certain depth the sedimentary deposits are melted by the heat to which they are subjected, but that the tremendous weight of the superincumbent water causes the mineral elements to consolidate once more into coherent rock-masses. He applied this theory of the melting and subsequent consolidation of rock-material universally to all pelagic and terrestrial sediments.

In the third part it is shown that the present land areas of the globe are composed of rock strata which have consolidated during past ages in the bed of the ocean. These are said to have been pushed upward by the expansive force of heat, while the strata have been bent and tilted during the upheaval. Hutton next describes the occurrence of crust fissures both during the consolidation of the rock and during the elevation of large areas and the subsequent inrush of molten rock or mineral ores into the fissures. He regards volcanoes as safety-valves during upheaval, which by affording exit at the surface for the molten rock-magma and superheated vapors prevent the expansive forces from raising the continents too far.

The evidences of volcanic eruption in the older geological epochs are next discussed. Hutton expresses the opinion that during the earlier eruptions the molten rock material spread out between the accumulated sediments or filled crust fissures, but did not actually escape at the surface; consequently that the older rock-magmas had solidified at great depths in the crust and under enormous pressure of superincumbent rocks. He calls the older eruptive rocks "subterraneous lavas" and includes among them porphyry and the whinstones (*eq.* trap-rock, greenstone, basalt, wacke, amygdaloidal rocks). Granite was also added in a later treatise. Hutton points out that the

subterraneous lavas have a crystalline structure, whereas those that solidify at the surface have a slaggy or vesicular structure.

In the fourth part Hutton concentrates attention on the preëxistence of older continents and islands from which the materials composing more recent land areas must have been derived. He likewise discusses the evidences of preexisting pelagic, littoral and terrestrial faunas from which existing faunas must have sprung. But, he continues, the existence of ancient faunas assumes an abundant vegetation, and direct evidence of extinct floras is presented in the coal and bituminous deposits of the Carboniferous and other epochs. Other evidence is afforded in the silicified trunks of trees that occasionally are found in marine deposits and have clearly been swept into the sea from adjacent lands.

Hutton then sets forth, in passages that have become classic in geological science, the slow processes of the subaerial denudation of land surfaces. He describes the effects of atmospheric weathering, of chemical decomposition of the rocks, of their demolition by various causes and the constant attrition of the soil by the chemical and mechanical action of water. He elucidates with convincing clearness the destructive physical, chemical and mechanical agencies that effect the dissolution of rocks, the work of running water in transporting the worn material from the land to the ocean, the steady subsidence of coarser and finer detritus that goes on in seas and oceans, lakes and rivers and the slow accumulation of the deposits to form rock strata. Hutton impresses upon his readers the vastness of the geological eons necessary for the completion of any such cycle of destruction and construction. In proof of this, he calls attention to the comparative insignificance of any changes that have taken place in the surface conformation of the globe within historic time.

Hutton was thus the great founder of physical and dynamical geology; he for the first time established the

essential correlation in the processes of denudation and deposition; he showed how, in proportion as an old continent is worn away, the materials for a new continent are being provided, how the deposits rise anew from the bed of the ocean, and another land replaces the old in the eternal economy of nature. The outcome of Hutton's argument is expressed in his words "that we find no vestige of a beginning—no prospect of an end."

When Hutton's theory of the earth's structure is compared with that of Werner and other contemporary or older writers the great feature which distinguishes it and marks its superiority is the strict inductive method applied throughout. Every conclusion is based upon observed data that are carefully enumerated, no supernatural or unknown forces are resorted to and the events and changes of past epochs are explained from analogy with the phenomena of the present age.

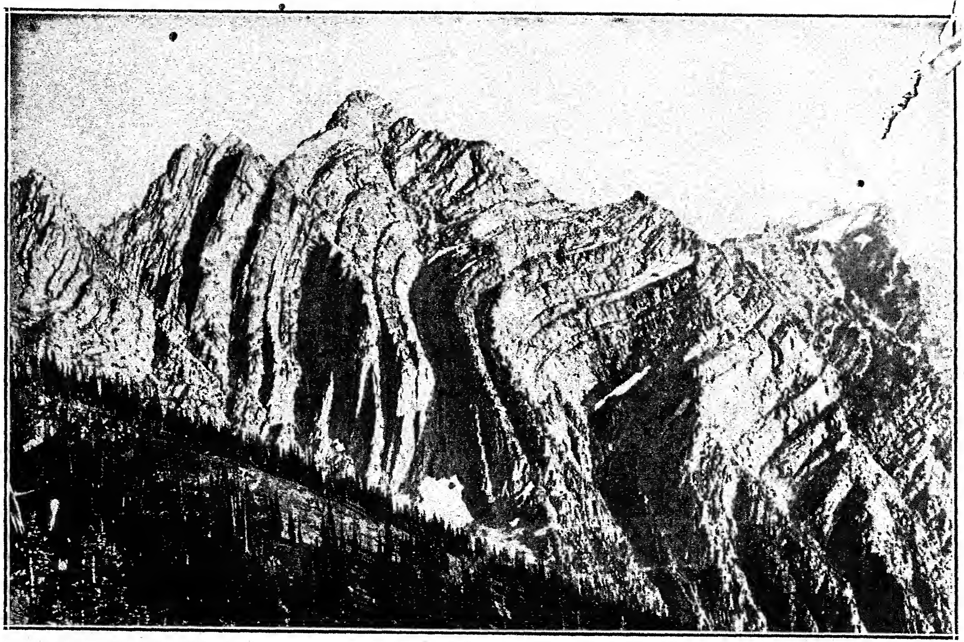
Hutton's explanation of the uprising of continents, owing to the expansive force of the subterranean heat, was not altogether new nor was it satisfactory. Neither had Hutton any clear conception of the significance of fossils as affording evidence of a gradual evolution. Yet in spite of these disadvantages, Hutton's "Theory of the Earth" is one of the masterpieces in the history of geology. Hutton's genius first gave to geology the conception of calm, inexorable nature working little by little—by the rain-drop, by the stream, by insidious decay, by slow waste, by the life and death of all organized creatures—and eventually accomplishing surface transformations on a scale more gigantic than was ever imagined in the philosophy of the ancients or the learning of the schools.

Hutton's scientific spirit and genial personality won for him many friends and adherents among the members of the Edinburgh academy. The most distinguished of these were Sir James Hall and the mathematician John Playfair. Hall (1762-1831) contested the validity of the opinion held by some of Hutton's opponents, that the melting of crystal-

line rocks would only yield amorphous glassy masses, Hall followed experimental methods; he selected different varieties of ancient basalt and lavas from Vesuvius and Etna, reduced them to a molten state and allowed them to cool. At first he arrived only at negative results, as vitreous masses were produced; but he then retarded the process of cooling and actually succeeded in obtaining solid, crystalline rock material. By regulating the temperature and the time allowed for the cooling and consolidation, Hall could produce rocks varying from finely to coarsely crystalline structure. And he therefore proved that under certain conditions crystalline rock could, as Hutton had said, be produced by the cooling of molten rock-magma.

Hall then put to the test Hutton's further hypothesis, that limestone also was melted and re-crystallized in nature. To this hypothesis the objection had been made that the carbonic acid gas must escape if limestone were brought to a glowing heat and the material would be converted into quicklime. This was Hall's first experience; then he devised another experiment. He introduced chalk or powdered limestone into porcelain tubes or barrels, sealed them and brought them to a very high temperature. The carbon dioxide gas could not escape under these conditions. The calcareous material was thus subjected to the enormous pressure of the imprisoned air and converted into a granular substance resembling marble.

Hall also conducted experiments on the bending and folding of rocks. He spread out alternate horizontal layers of cloth and clay, placed a weight upon them and subjected them to strong lateral pressure. These and similar experiments have been often repeated within recent years, and it is well known that in this way phenomena of deformation can be artificially produced which bear the closest resemblance to the phenomena of rock deformation under natural conditions. In his desire to vindicate Hutton's



TRUNCATED AND FOLDED RIDGE, MONTANA.

theory, Hall became himself one of the great founders of experimental geology.

At the same time John Playfair (1748-1819), whose interest in geology had been roused by Hutton's companionship, became the enthusiastic exponent of Hutton's theory. It was Playfair's literary skill that opened the eyes of scientific men to the heritage Hutton had left for them. He did for Hutton's teaching what fifty years after was done for Darwin's doctrines by the gifted Huxley.

Playfair's "Illustration of the Huttonian Theory" is a lucid exposition of that theory in the form of twenty-six

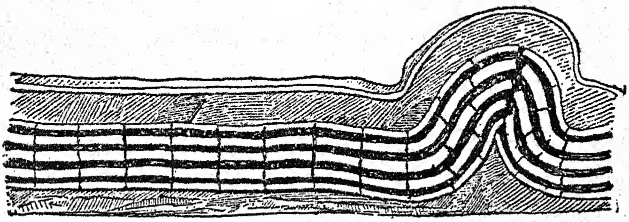


Fig. 8 —Model Showing Slip of Folded Strata. (Willis.)

ample discussive notes. Playfair's work differs in no essential point from the views held by his master and friend, but many subjects which receive a subordinate treatment in the "Theory of the Earth" are brought into prominence by Playfair and placed for the first time on a firm scientific basis. His treatment of valley and lake erosion is extremely able. And Playfair was the first geologist who realized that the huge erratic blocks might have been carried to their present position by former glaciers. His insight in this respect would alone have won for him a lasting fame, for the erratics on Alpine slopes and plains had long been observed by geologists and an explanation vainly sought.

CHAPTER V

DEVELOPMENTS OF MODERN GEOLOGICAL KNOWLEDGE

WITH Hutton's work as a basic point Geology took new life. The theory in the main was sound; it remained but to classify the results of the past and to prepare for the reception of the observations of the future. The nineteenth century witnessed the great development of the processes of the earth's formation which stratigraphical geology sets forth.

Jean-Baptiste Pierre Antoine de Monet, Chevalier de Lamarck (1744-1829), came of an ancient but somewhat decayed family and was born in a village of Picardy as the eleventh and youngest child of the Seigneur de Béarn. The earlier part of his career was devoted first to soldiering, then to Botany and then to Zoölogy. Tho Lamarck wrote little on Geology, the extent to which he had pondered over the problems of the science, which in his time had hardly taken definite shape, is well illustrated by the little volume which he published in 1802 under the title of "Hydrogéologie." He recognised that nothing can ultimately resist the alternating influence of wetness and drought, combined with that of heat and cold, and that the disintegration of mineral substances by these atmospheric conditions prepares the way for the erosive action of running water in all its various forms.

To him it was clear that every mountain which had not been erupted by volcanic action or some other local catastrophe, had been cut out of a plain, so that the mountain

summits represent the relics of that plain, save in so far as its level has been lowered in the general degradation. He admits that in many mountains the component strata are often vertical or highly inclined. But he will not on that account believe in any universal catastrophe, such as had been demanded by many previous writers and was still loudly advocated in his own time by his fellow-countryman, Cuvier.

Lamarck conceived the ocean basin to owe its existence and preservation to the perpetual oscillation of the tides and partly also to a general westerly movement of the water. He supposed the tidal oscillation to be a gigantic force which has actually eroded the basin and now prevents it from being shallowed, through the deposit of land-derived sediment, by continually scouring this sediment out and casting it up along the more sheltered shores of the land. No one before his day had been able to follow so clearly the successive stages through which organic remains pass until they become crystalline stone, presenting no trace of their original organic structure. During the last ten years of his long life he suffered from total blindness and had to rely on the affectionate devotion of his eldest daughter for the completion of such works as he had in progress before his eyesight failed. The world is becoming more conscious now of what it owes to the genius of this illustrious naturalist. Among those students of science who have most reason to cherish his memory geologists should look back gratefully to his services in starting the science of paleontology, in propounding the doctrine of evolution and in affirming with great insight some of the fundamental principles of modern geology.

Georges Cuvier (1769-1832), a French naturalist and founder of the science of comparative anatomy, effected a great and notable advance in the science of Paleontology. It is to Cuvier that the world owes the first systematic application of that science of comparative anatomy, which he himself did so much to place upon a sound basis, to the

study of the bones of fossil animals. He demonstrated that extinct animals could be "reconstructed" from fragmentary remains by applying the law of "correlation of growth." But it is true, as pointed out by Professor Huxley, that he placed more confidence and security in this law than its empiric nature and exceptions would justify.

Cuvier in his work on the geology of the Paris basin was greatly assisted by his friend, Alexandre Brongniart. Brongniart was early trained in scientific pursuits. In 1807 he published a treatise on mineralogy, which became a standard work. He became professor of mineralogy at the Jardin des Plantes and in 1808 appeared the work on the Paris basin. Cuvier and Brongniart drew up a systematic table of the succession of stratigraphical horizons in accordance primarily with the sequence of the deposits in the ground and with the particular fossils characterizing each group of deposits; the varieties of rock and the thicknesses and distribution of different deposits were also fully considered and carefully mapped.

Omalius d'Halloy (1783-1875), the Belgian geologist, made an examination of the formations in Auvergne, Velay and in parts of Italy and Germany, and in all cases proved conclusively that the fossil remains had been imbedded in the deposits of fresh-water marshes and were not remains which had been accidentally swept into marine deposits. The Belgian geologist supplemented the observations of Cuvier and Brongniart with great success.

Early in his career D'Halloy had regarded the position of the strata, their horizontal, slightly or highly inclined, or vertical position, of great importance in determining the age of the strata. He thought the horizontal strata corresponded to Werner's "Flötz formations" and all inclined strata to Werner's "Transitional formations." But his subsequent visit to the Alps and Jura mountains caused him to modify these views.

The fearful earthquake which destroyed Lisbon in 1755 was made the subject of a large number of scientific in-

quiries into the causes of earthquakes. William Stukeley's theory, attributing earthquakes to electrical disturbances, gained a certain amount of support abroad. Another Englishman, Rev. John Michell, suggested that sudden expansion of vapors enclosed in fissures and cavities of the earth's crust caused earthquakes and volcanoes, the upheaval of mountain systems and the deformation of rocks.

In 1760 he published a series of observations on earthquakes and mountain structure. This paper was accompanied by an ideal section through a mountain system, showing a central core composed of the crystalline massive rocks, on either side a succession of uptilted and upheaved strata covered in their turn by younger, slightly tilted or horizontal deposits composing the neighboring plains. Michell, however, did not draw any general conclusions, yet he deservedly ranks as the great pioneer of the modern science of Seismology.

Another English observer was John Whitehurst (1713-1788), who published in 1778 an "Inquiry into the Original State and Formation of the Earth." This work was the last effort of the fantastic English school of cosmogonists. Amid absurd speculations as to the condition of chaos and other equally visionary topics, he wrote well on organic remains and showed that he clearly grasped the stratigraphical succession of the formations in Derbyshire and other parts of England. "The strata invariably follow each other," he remarks, "as it were, in alphabetical order," and tho they may not be alike in all parts of the earth, nevertheless "in each particular part, how much soever they may differ, yet they follow each other in a regular succession." He was one of the many who were interested in the origin of the basaltic pillars of the Giants' Causeway and who endeavored to interpret their origin.

One of the most active and interesting of those who devoted themselves with ardor to the study of the Italian volcanoes was Gratet de Dolomieu (1750-1801). His attention was especially drawn to the active and extinct

volcanoes of the Mediterranean basin. As far back as 1776 he made the announcement that he had found in Portugal evidence of volcanoes older than certain mountains of limestone—a statement which he supplemented in 1784 with further evidence from Sicily, proving the intercalation of ancient lavas among stratified deposits. Dolomieu confirmed the igneous origin of basalt rock, regarding it as a variety of lava for the most part associated with submarine eruptions. His name is perpetuated in the name of the "Dolomites," given to the beautiful district in South Tyrol, south of the Puster Valley.

Elie de Beaumont was another scientific Frenchman who interested himself in mountains. He was one of the most enthusiastic adherents of the Vulcanist doctrines. Toward the end of an article on mountains, which appeared in the Annales of the French Academy, are a few remarks on mountain structure. Brief altho they are, the remarks on the influence of the slow cooling of the earth on surface conformation and the origin of furrows and fissures are at once recognised by a reader of the present day as the starting-point of the modern views on mountain structure. Later appeared his three volume treatise on mountain systems. He points out that in virtue of the continued cooling of the planet the radius is shortened and the crust is affected by a general centripetal movement; that is, the volume of the globe becoming less, the crust is drawn in toward the center of gravity.

Delesse meanwhile had calculated 1,340 meters as the amount by which the earth's radius had already been shortened; in other words, the earth's crust in the course of the geological epochs had approached the earth's center by a distance about equal to the height of Chimborazo or the Himalayas above sea-level.

William Smith (1769-1839), an English engineer, was the first to recognise the importance of fossils in their full significance as a means of determining the relative age of strata. Born in a county that was unusually rich in

fossil remains, he had in his boyhood abundant opportunity of observing and collecting. For twenty-five years he continued his investigations in all parts of England, entered his observations in colored geological maps and compiled them from time to time in the form of tables or as explanatory notes to his maps.

About 1800 he began the preparation of a geological map of England and Wales on a scale of five miles to one inch, which occupied nearly fifteen years of his life and which was supplemented by separate maps of the counties published in color on twenty-one sheets. Smith's map is the first attempt to represent on a large scale the geological relations of any extensive tract of ground in Europe. It was a magnificent achievement and was the model of all subsequent geological maps. For English Geology, the publication of the map was the starting-point of a new régime. The Geological Society of London conferred upon him the Wollaston medal, and he well deserves to be called the "Father of English Geology."

There is yet another name that deserves to be remembered in any review of the early efforts to group the Secondary formations—that of Thomas Webster (1773-1844). As far back as 1811 this clever artist and keen-eyed geologist began a series of investigations of the coast sections of the Isle of Wight and of Dorset and continued them for three years. He clearly defined each of the leading subdivisions of the Cretaceous series and prepared the way for the admirable later and more detailed works of William Henry Fitton (1780-1861), to whom Geology is indebted for the first detailed and accurate determination of the succession of strata and their distinctive fossils, from the base of the Chalk down into the Oolites, in the south of England and the neighboring region in France. More particularly he showed the relations and importance of the Greensand formations, his memoirs on which are now among the classics of English geology.

The early progress of stratigraphical geology in Britain includes the important influence exerted by the Geological Society of London, which was founded in 1807 "to investigate the mineral structure of the earth." At that time the warfare between the Neptunists and Plutonists still continued, but there were many men interested in the study of geological subjects who were weary of the conflict of hypotheses and who would fain devote their time and energy to the accumulation of facts regarding the ancient history of the globe rather than to the elaboration of theories to explain them. A few such inquirers formed themselves into the Geological Society and soon attracted others around them until, in a few years, they had established an active institution which became a center for geological research and discussion, published the contributions of its members in quarto volumes and eventually was incorporated by royal charter as one of the leading scientific bodies of the country. This society, which has been the parent of others in different countries, continues to flourish, and its publications, extending over nearly a century, contain a record of original researches which have powerfully helped the progress of all branches of geology. Besides their papers issued by the society, some of the early members published separate works which greatly advanced the cause of their favorite science. Among these early independent treatises perhaps the most important was the "Outlines of the Geology of England and Wales" by W. D. Conybeare (1787-1857) and W. Phillips (1775-1828), which appeared in 1822. In this volume all that was then known regarding the rocks of the country, from the youngest formations down to the Old Red Sandstone, was summarized in so clear and methodical a manner as to give a definite impulse to the cultivation of Geology in England.

The amount of ascertained fact regarding the structure and history of the earth was every year increasing at so rapid a rate that it became necessary to prepare digests of

it for the use of those who wished to be informed on these subjects or to keep pace with the advance of knowledge. Hence arose in different countries text-books, manuals and other general treatises wherein an account was given of the facts and principles of geological science.

But of all the English writers of general treatises on geology, the first place must undoubtedly be assigned to Charles Lyell (1797-1875), who exercised a profound influence on the geology of his time in all English-speaking countries. Adopting the principles of the Huttonian theory, says Sir Archibald Geikie, in his 'Founders of Geology,' he developed them until the original enunciator of them was nearly lost sight of.

"With unwearied industry he marshalled in admirable order all the observations that he could collect in support of the doctrine that the present is the key to the past. With inimitable lucidity he traced the operation of existing causes and held them up as the measure of those which have acted in bygone time. He carried Hutton's doctrine to its logical conclusion, for not only did he refuse to allow the introduction of any process which could not be shown to be a part of the present system of Nature, he would not even admit that there was any reason to suppose the degree of activity of the geological agents to have ever seriously differed from what it has been within human experience. He became the great high priest of Uniformitarianism—a creed which grew to be almost universal in England during his life, but which never made much way in the rest of Europe, and which in its extreme form is probably now held by few geologists in any country." Lyell's "Principles of Geology" will, however, always rank as one of the classics of Geology and must form an early part of the reading of every man who would wish to make himself an accomplished geologist. The last part of this work was ultimately published as a separate volume, with the title of "Elements of Geology," in which a large space was devoted to an account of the stratified fossiliferous

formations. This treatise, diligently kept up to date by its author, continued during his lifetime to be the chief English exposition of its subject and the handbook of every English geologist.

Lyell's function was mainly that of a critic and exponent of the researches of his contemporaries and of a philosophical writer thereon, with a rare faculty of perceiving the connection of scattered facts with each other and with the general principles of science. As Ramsay once remarked, "We collect the data and Lyell teaches us to comprehend the meaning of them." But Lyell, tho he did not, like Sedgwick and Murchison, add new chapters to geological history, nevertheless left his mark upon the nomenclature and classification of the geological record. Conceiving, as far back as 1828, the idea of arranging the whole series of Tertiary formations in four groups, according to their affinity to the living fauna, he established, in conjunction with Deshayes, who had independently formed a similar opinion, the well-known classification into Eocene, Miocene and Pliocene. The scheme was a somewhat artificial one, and the original percentages have had to be modified from time to time to accord with later discoveries, but the terms have kept their place and are now firmly planted in the geological language of all corners of the globe.

So far no complete subdivision of the immense complex of strata between the crystalline schists and the coal measures had been attempted, and it was this gigantic task that the two British geologists, Adam Sedgwick (1785-1873) and Roderick Murchison (1792-1871), set themselves to accomplish in the British area. Unfortunately the scarcity of fossils made it still impossible for Sedgwick to establish paleontological subdivisions. Murchison was more fortunate. While his colleague was engaged in the examination of the oldest group of the Transitional series Murchison began his investigation of the series in descending order from the upper members to the lower. He

examined the exposures of Old Red Sandstone and the rocks immediately below it, which occur on the eastern and southern borders of Wales.

Murchison found fossils in abundance, and in a couple of years was able to lay before the Geological Society a complete paleontological sequence in the upper portion of the Transitional formations. At first Murchison had called these higher members examined by him an "Upper fossiliferous graywacke series," but in the year 1835, in compliance with the strongly expressed wish of Elie de Beaumont, he proposed the name "Silurian System" as a special designation for the upper members. And as the older members of the Transitional series examined by Sedgwick in Cumberland and North Wales could not be identified with any of the members in the Silurian system of Murchison, the term of "Cambrian Series" was proposed by Sedgwick in 1836 for these older members, and this term was accepted by Murchison.

Murchison distinguished three chief divisions in the Silurian system: Upper Silurian, comprising the Ludlow Rocks and Wenlock Limestone; Lower Silurian, comprising the Caradoc Sandstone and Llandeilo Flags; and Cambrian. He found it impossible at the time to fix a definite paleontological horizon as the lower limit of the Silurian system, and Sedgwick also could not assign any paleontological or other feature which would determine the upper limit of the Cambrian series. Nevertheless the recognition of the Silurian and Cambrian systems was one of the most important advances that have been made in stratigraphy.

The vast and varied series of rocks which have now been ascertained to underlie the oldest Cambrian strata have undergone much scrutiny during the last half century, and their true nature and sequence are beginning to be understood. The first memorable onward step in this investigation was taken in North America by William Edmond Logan (1798-1875). He recognized the existence of at least three vast systems older than the oldest fos-

siliferous formations. He may be said to have inaugurated the detailed study of Pre-Cambrian rocks. Subsequent investigation has shown the structure of the regions which he explored to be even more complicated and difficult than he believed it to be, but he will ever stand forward as one of the pioneers of Geology, who, in the face of incredible difficulties, first opened the way toward a comprehension of the oldest rocks of the crust of the earth.

Charles Darwin (1809-1882) contributed several valuable works to the literature of Geology. The two geological chapters in his "Origin of Species" produced a great revolution in geological thought. To most of the geologists of his day Darwin's contention for the imperfection of the geological record and his demonstration of it came as a kind of surprise and awakening. They had never realized that the history revealed by the long succession of fossiliferous formations, which they had imagined to be so full, was in reality so fragmentary.

Lord Kelvin (Sir William Thomson) (1824-1907) attributed great importance to the enormous pressure existing in the interior of the earth and the consolidation of the nucleus from this cause. He ascribed to the body of the earth a degree of rigidity intermediate between that of steel and of glass. Starting from the nebular theory, Lord Kelvin supposed that the cooled and thereby heavier masses sank inward and formed an initial central nucleus, which always extended toward the periphery as the earth's mass continued to cool, until finally almost the whole earth became rigid.

Sir Andrew Crombie Ramsay (1814-1891), the noted Scotch geologist, devoted his attention to the physical side of Geology. His dislike for Paleontology and Petrology sometimes led him into serious theoretical errors, thereby impairing the value of his work.

Suess' contributions to Geology opened up a new path in geological inquiry and laid the foundation for what is now frequently termed the "New Geology," deal-

ing with the construction and relations of continents and mountain ranges, the dynamics of volcanoes and earthquakes, and the general movement of the earth's crust. In 1885 he began his "Antlitz der Erde," which is a masterful exposition of the relations of the dominant features of the earth's surface, and the first luminous efforts to correlate their multiform aspects and give to them their true geological expression. He was one of the recognized authorities on earthquakes and volcanoes.

Jean Louis Rodolphe Agassiz (1807-1873) was born in Switzerland, and rose to distinction by his scientific work in Europe, but he went to the United States when he was still only forty-two years of age, and spent the last twenty-seven years of his life as an energetic and successful leader of science in his adopted home. His fame as a geologist is due to the important part he took in founding the modern school of glacial geology.

Tracing the distribution of the erratic blocks above the present level of the glaciers, and far beyond their existing limits, he connected these transported masses with the polished and striated rock-surfaces which were known to extend even to the summits of the southern slopes of the Jura. He was led to conclude that the Alpine ice, now restricted to the higher valleys, once extended into the central plain, crossed it, and even mounted to the southern summits of the Jura chain.

Before Agassiz took up the question there were two prevalent opinions regarding the transport of the erratics. One of these called in the action of powerful floods of water, the other invoked the assistance of floating ice. Agassiz combated these views with great skill. But the conclusions at which he arrived seemed to most men of the day extravagant and incredible. Even a cautious thinker like Lyell saw less difficulty in sinking the whole of Central Europe under the sea, and covering the waters with floating icebergs, than in conceiving that the Swiss glaciers were once large enough to reach to the Jura."

Men shut their eyes to the meaning of the unquestionable fact that, while there was absolutely no evidence for a marine sumbergence, the former track of the glaciers could be followed mile after mile, by the rocks they had scored and the blocks they had dropped, all the way from their present ends to the far-distant crests of the Jura.

William Nicol was a lecturer on Natural Philosophy at Edinburgh in the early part of last century. Among his inventions was the famous prism of Iceland spar that bears his name. Every petrographer will acknowledge how indispensable is this little piece of apparatus in his microscopic investigations. He may not be aware, however, that it was the same hand that devised the process of making thin slices of minerals and rocks, whereby the microscopic examination of these substances became possible. At last Henry Clinton Sorby came to Edinburgh. He soon began to put the method of preparing thin slices into practice, made sections of mica-schist, threw his whole energy into the investigation for several years, and produced at last in 1858 the well-known memoir, "On the Microscopical Structure of Crystals," which marks one of the most prominent epochs of modern geology.

At this time the discoveries of Darwin turned the attention of the world to the question of the Origin of Species, and the geologists of the world, for the third quarter of the nineteenth century, spent most of their energy along paleontological lines, and the results will be found in this volume under the descriptive heading, "Historical Geology." In this subject the zoologist and the geologist work hand in hand. The geologist assists his brother scientist by tracing the order in which the strata were deposited in which fossils were found, and the paleontologist checks up the work by showing the development in complexity of the animals to which those bones belonged.

As the nineteenth century drew to its close, and the paleontological record was seen to be well in hand, an

entirely new set of problems was undertaken by geologists. These dealt with the Age of the Earth. For centuries untold the entire age of the earth had been supposed to be only a few thousand years. When, however, Lyell predicated 100,000 years for the period of Man alone, when all the paleontologists demanded periods of millions of years for the gradual development of species, and when the astronomers and physicists demanded tens

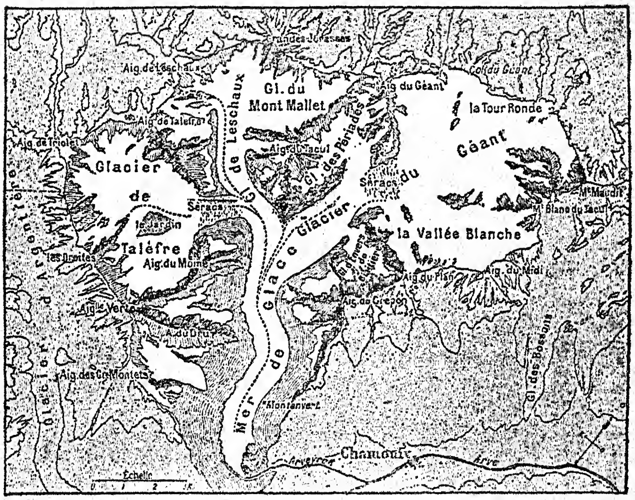


Fig. 9 —A Typical Glacier System.

of millions of years for an explanation of earth conditions as their investigations showed them to be, it became evident that there was urgent need for a revision of the estimates of the age of the earth.

The first modern attempt to solve this problem was made by John Phillips, who, in 1860, introduced the use of various geological processes as vast time clocks.

Among these methods the most general has been that of finding the time required to deposit a certain depth of material under certain conditions (such as the deposition of ooze on the sea-floor), then to calculate the thickness of the rocks of the earth's crust, and, by multiplying one by the other, to arrive at the length of time needed to lay down the sedimentary rocks. Such a system of calculation, however, can only be vaguely approximate, for, in the first place, the rate of deposit differs very widely, and in the second place, there is no means of determining the speed of deposition during the earlier periods of the earth's history. In addition to this, pressure on rocks causes a shrinkage. As the pressure is not the same at any two places, and as the variability of shrinkage in rocks is high, there is a further number of uncertainties added to the problem.

Professor Joly of Dublin, in 1881, gave figures for the Age of the Earth, based on the saltness of the sea, which, of course, is becoming steadily salter. There are about 12 quadrillion tons of common salt in the sea and 156 million tons are added every year. This estimate makes the ocean 77 million years old. But there are only about 454 trillion tons of potassium (which, like the salt, has been dissolved from the rocks) and 37 million tons are added annually. This would make the ocean only 12 million years old. The potassium, however, is taken up with iron in the making of glauconite, but the amount thus consumed is not enough to explain the difference between 12 and 17 million years. Besides all which, it is a pure assumption that the primeval ocean was free of dissolved materials. Still, by this method, Professor Joly gave a tentative estimate of the age of the oceans at 100 million years, and in the latest work along this line, Dr. A. R. Holmes in 1913 concluded that the limits would be between 210 and 340 million years.

The newer estimates of the age of the earth deal neither with sedimentation nor the saltness of the sea, but with

questions of radio-activity. This discussion is connected historically with the estimates made by the astronomers and physicists, notably Lord Kelvin, who first in 1876 and again in 1897, calculated the earth's age from the fuel consumption of the sun and the internal temperatures of the earth. His revised figures were from 20 million to 40 million years for the whole of the earth's existence. Huxley promptly and bluntly denied this, declaring that "mathematics was not a proof, but a process; it was a mill that ground nothing but what was put into it."

Professor Perry, in 1903, nullified Lord Kelvin's figures by showing that the great physicist had made an unwarranted assumption in supposing that the materials in the interior of the earth conducted heat at exactly the same speed as the rocks in the crust. A little later, in connection with Professor Moulton's work, it was shown that the interior material conducts heat at least four times as quickly.

All this line of argument, however, passed into an entirely new phase with the discovery of radium and of radio-active rocks. The amount of radio-active rock, its rate of disintegration, the amount of heat emitted by the process—all these are new factors. In spite of the difficulties, Professor Strutt, in 1909, by a combined estimate from the amount of helium in fragments of phosphate and fossil bones and by tests of minerals such as iron ores and zircons, deduced the earth's age as approximately four billion years. It is still a disputed point, but the balance of authorities may be said to confirm the estimate of one billion years since the primitive rocks were first laid down.

Without a doubt the most important geological advance made during the past two centuries was the formulation of the new theory of the balance of the different areas of the earth's crust. This is known as isostasy, and was put forth by Professor Dutton in 1889. In 1909 Hayford, of the U. S. Geodetic Survey, closed a very complete in-

vestigation of isostatic conditions in the United States, and concluded that "The United States is not maintained in its position above sea-level by the rigidity of the earth, but is, in the main, buoyed up, floated, because it is composed of material of deficient density." The theory has the endorsement of Professor T. C. Chamberlin, one of the most eminent names in American geology.

This conception of the earth as a rigid crust floating on a fluidable foundation, however, appears to have been confronted by another problem. If the foundations are fluid, why do not the mountains sink into this fluid interior and thus bring the face of the earth to a uniform level? Dutton suggested, and modern science has supported his view, that the reason for the comparative heights and depths of mountains and ocean beds is due to the relative density of the rocks which compose them. Thus the rock masses of the Himalayas are far lighter than the rocks under the Indian Ocean, so much lighter, in fact, that their 25,000 extra feet of height do not cause the mass to be heavier than the weight of the ocean and the rock under the ocean floor, when both are measured through the outer crust to fluidable interior, nearly a hundred miles below.

Dr. Hecker, in 1911, by very careful experiments on the ocean floor, showed that the rocks were actually more dense, as the theory required. Hayford, Barrell and others in America showed that isostasy holds true for the whole continent except a few areas here and there, none of them larger than a county. The compensation is not exact, for the crust has considerable rigidity; but it is very close. With the advance in radio-activity and the growing authoritative support of isostasy, Geology in the Twentieth Century has advanced with tremendous strides.

CHAPTER VI

COMPOSITION OF THE EARTH

A DISCUSSION of the geological changes which this planet has undergone ought to be preceded by a study of the materials which enter into its composition. This branch of geology is technically termed Geognosy. The earth may be considered as a globe, which has cooled sufficiently to have a solid crust, enclosed in two envelopes or shells, the inner one of water covering about three-fourths of the globe and the outer one of gas completely enveloping the whole. This outer envelope of gas is known as the atmosphere, the water is called the hydrosphere, and the solid globe is the lithosphere or rock sphere.

There is every reason to believe that the present gaseous and liquid envelopes of the planet are only a portion of the original mass of gas and water with which the globe was invested. As Sir Archibald Geikie says in his 'Text Book of Geology,' "Fully a half of the outer shell or crust of the earth consists of oxygen, which probably once existed in the primeval atmosphere. The extent, likewise, to which water has been abstracted by minerals is almost incredible. It has been estimated that already one-third of the whole mass of the ocean has been thus absorbed. Eventually the condition of the planet will probably resemble that of the moon—a globe without air, or water, or life of any kind.

"The gaseous envelope to which the name of atmosphere is given extends from the earth's surface to a distance

which has been variously estimated, according to the methods of observation employed. From the phenomena of twilight it may be inferred that the atmosphere must be at least 45 miles thick. The aurora indicates a sensible atmosphere at 100 miles, and clouds have been detected at heights of nearly 100 miles. Meteorites, which become incandescent by friction against our atmosphere, sometimes appear at heights of 150 miles. We may therefore infer that the atmosphere stretches for at least that distance from the earth's surface, and probably in a state of extreme tenuity much farther. At sea-level the mean pressure of the atmosphere is about 14¾ pounds per square inch."

Many speculations have been made regarding the chemical composition of the atmosphere during former geological periods. There can indeed be no doubt that it must originally have differed very greatly from its present condition. It has been contended, for instance, that originally there was little or no free oxygen in the atmosphere, which may have consisted mainly of nitrogen, carbonic acid, and aqueous vapor. Besides the abstraction of the oxygen which now forms fully a half of the outer crust of the earth, the vast beds of coal found all over the world, in geological formations of many different ages, doubtless represent so much carbon-dioxide (carbonic acid) once present in the air.

As now existing, the atmosphere is considered to be normally a mechanical mixture of nearly 4 volumes of nitrogen and 1 of oxygen ($N 79.4$, $O 20.6$), with minute proportions of carbon-dioxide and water-vapor and still smaller quantities of ammonia and the powerful oxidizing agent, ozone. These quantities are liable to some variation according to locality. The mean proportion of carbon-dioxide is about 3.5 parts in every 10,000 of air.

The other substances in the air are gases, vapors and solid particles. Of these, by much the most important is the vapor of water, which is always present, but in

very variable amount according to temperature. It is by this vapor, together with the carbon-dioxide and suspended dust-particles, that the radiant heat in the atmosphere is absorbed. The water-vapor condenses into dew, rain, hail, and snow, and is thus of paramount importance in the great series of surface agencies which play so large a part in the geological changes of the earth. In analyzing the air carried down in solution in rain water, the atmospheric gases, together with ammonia, nitric, sulphurous and sulphuric acids, chlorides, various salts, solid carbon, inorganic dust, and organic matter, have been detected.

The fine microscopic dust so abundant in the air is no doubt for the most part due to the action of wind in lifting up the finer particles of disintegrated rock on the surface of the land. As a geological agent, the atmosphere effects changes by the chemical reactions of its constituent gases and vapors, by its varying temperature, and by its motions.

Rather less than three-fourths of the surface of the globe (or about 144,712,000 square miles) are covered by the irregular sheet of water known as the Sea. Within the last few decades much new light has been thrown upon the depths, temperatures, and biological conditions of the ocean-basins, more particularly by the Lightning, Porcupine, Challenger, Tuscarora, Blake, Gazelle, and other expeditions fitted out by the British, American, German, Norwegian and Swedish Governments. The water of the ocean is distinguished from ordinary terrestrial waters by a higher specific gravity, and the presence of so large a proportion of saline ingredients as to impart a strongly salt taste. The average density of sea-water is about 1.026, but it varies slightly in different parts even of the same ocean.

The greater density of sea-water depends, of course, upon the salts which it contains in solution. At an early period in the earth's history, the water now forming the

ocean, together with the rivers, lakes, and snowfields of the land, existed as vapor, in which were mingled many other gases and vapors, the whole forming a vast atmosphere surrounding the still intensely hot globe. Under the enormous pressure of the primeval atmosphere, the first condensed water might have had a temperature little below the critical one. In condensing, it would carry down with it many substances in solution. The salts now present in sea-water are to be regarded as partially derived from the primeval constitution of the sea, and thus it may be inferred that the sea has always been more or less saline.

But it is manifest that, whatever may have been the original composition of the oceans, they have for a vast section of geological time been constantly receiving mineral matter in solution from the land. Every spring, brook, and river removes various salts from the rocks over which it moves, and these substances, thus dissolved, eventually find their way into the sea. Consequently, sea-water ought to contain more or less traceable proportions of every substance which the terrestrial waters can remove from the land—in short, of probably every element present in the outer shell of the globe, for there seems to be no constituent of the earth which may not, under certain circumstances, be held in solution in water.

The average proportion of saline constituents in the water of the great oceans far from land is about three and a half parts in every hundred of water; and the proportions of the different chemical elements in the composition of the waters of the ocean as a whole are much as follows: Oxygen, 85.79; hydrogen, 10.67; chlorine, 2.67; sodium, 1.14; magnesium, 0.14; calcium, 0.05; potassium, 0.04; sulphur, 0.09; bromine, 0.008; and carbon, 0.002.

Within the atmospheric and oceanic envelopes lies the inner solid globe. The only portion of it which, rising above the sea, is visible to Man, and forms what is termed

Land, occupies rather more than one-fourth of the total superficies of the globe, or about 52,745,000 square miles.

It was formerly the prevalent belief that the exterior and interior of the globe differ from each other to such an extent that, while the outer parts are cool and solid, the vastly more enormous inner intensely hot part is more or less completely liquid. Hence the term "crust" is applied to the external rind in the usual sense of that word. This crust was variously computed to be ten, fifteen, twenty, or more miles in thickness.

The earth's crust is composed of mineral matter in various aggregates included under the general term Rock. A rock may be defined as a mass of matter composed of one or more simple minerals, having usually a variable chemical composition, with no necessarily symmetrical external form, and ranging in cohesion from mere loose débris up to the most compact stone. Granite, lava, sandstone, limestone, gravel, sand, mud, soil, marl and peat, are all recognised in a geological sense as rocks.

Direct acquaintance with the chemical constitution of the globe must obviously be limited to that of the crust, tho by inference it may be possible eventually to reach highly probable conclusions regarding the constitution of the interior. Chemical research has discovered that some seventy-five simple or as yet undecomposable bodies, called elements, in various proportions and compounds, constitute the accessible part of the crust. Of these, however, the great majority are comparatively of rare occurrence. The crust is mainly built up of about twenty elements, which may be arranged in two groups, metalloids and metals. Of the metalloids, oxygen and silicon represent 75 per cent. of the matter in the world, hydrogen, carbon, phosphorus, sulphur, chlorine, fluorine and nitrogen being less than 1½ per cent. all together; while among the metals, aluminum is 7.45 per cent.; iron, 4.2; calcium, 3.25; magnesium, 2.35; potassium, 2.35; sodium, 2.40, and titanium, manganese, barium,

strontium, chromium, nickel and lithium together are less than one-half of one per cent. Of the other elements, upward of fifty in number, the proportions are so small that probably not one of them equals as much as one-hundredth of one per cent. of the whole crust. Yet they include gold, silver, copper, tin, lead and the other useful metals, iron excepted. It will be observed that of the accessible part of the globe over three-fourths consist of metalloids and less than one-fourth of metals. It is also interesting to note that 97 per cent. of the crust is made up of the 10 most abundant elements; that is, of the 3 first metalloids and the 7 first metals. Silicon is never found free, but always combined with oxygen.

Comparatively few of the elements occur free, but occur in more or less complex compounds with one or more others. The combinations which enter most largely into the composition of the earth's crust can best be determined from the collation of a sufficiently large number of chemical analyses of the more representative rocks of the earth's crust. Such a determination has been made by Mr. F. W. Clarke from the mean of 830 analyses of typical samples from the older or primitive part of the crust and is expressed. The following are the chief: Silica (SiO_2) 59.71 per cent., alumina (Al_2O_3) 15.41, ferric oxide (Fe_2O_3) 2.63, ferrous oxide (FeO) 3.52, lime (CaO) 4.90, magnesia (MgO) 4.36, potash (K_2O) 2.80, soda (Na_2O) 3.55, water (H_2O) 1.52, titanic acid (T_iO_2) 0.60, and phosphoric acid (P_2O_5) 0.22.

In a broad view of the arrangement of the chemical elements in the external crust, the speculation of Durocher may be noticed here. He regarded all rocks as referable to two layers or magmas co-existing in the earth's crust, the one beneath the other, according to their specific gravities. The upper or outer shell, which he termed the acid or siliceous magma, contains an excess of silica, and has a mean density of 2.65. The lower or inner shell, which he called the basic magma, has from six to eight times

more of the earthy bases and iron-oxides, with a mean density of 2.96. To the former he assigned the early plutonic rocks, granite, felsite, etc., with the more recent trachytes; to the latter he relegated all the heavy lavas, basalts and diorites.

The rocks of the earth's crust are made up of compounds of the elements which have just been mentioned. These compounds geologists call minerals. Scott, in his 'Introduction to Geology,' defines a mineral as a natural, inorganic substance, which has a homogeneous structure, definite chemical composition and physical properties, and usually a definite crystal form. The number of known minerals is large, and constantly increasing, but only a few enter in any important way into the constitution of the earth's crust.

Having considered the composition of the atmosphere, sea, and solid crust, the general features of the earth's surface require attention. The late Professor Dana, of Yale, briefly summarizes the important physical features of the earth in his 'Text Book of Geology,' wherein he says: "The earth has a circumference of 24,899 miles. Its form is that of a sphere flattened at the poles, the equatorial diameter, 7,926 miles, being about 26⅔ miles greater than the polar diameter." About eight-elevenths of the earth's surface, or 144,000,000 square miles, is depressed below the rest, and occupied by the sea. This sunken part of the crust is called the oceanic basin, and the large areas of land are called the continents or continental plateaus. The area of the dry land is about 52,745,000 square miles.

"Nearly three-quarters of the land is situated in the northern hemisphere, and very nearly three-fifths of the oceanic basin in the southern hemisphere. The dry land may be said to be grouped about the North Pole, and to stretch southward in two masses, an Oriental, including Europe, Asia, Africa, and Australasia, and an Occidental, including North and South America. The ocean is

gathered in a similar manner about the South Pole, and extends northward in two broad areas separating the Occident and Orient, namely, the Atlantic and Pacific Oceans, and also in a third, the Indian Ocean, separating the southern prolongations of the Orient, namely, Africa and Australasia. The Orient is made, by this arrangement, to have two southern prolongations, while the Occident, or America, has but one. This double feature of

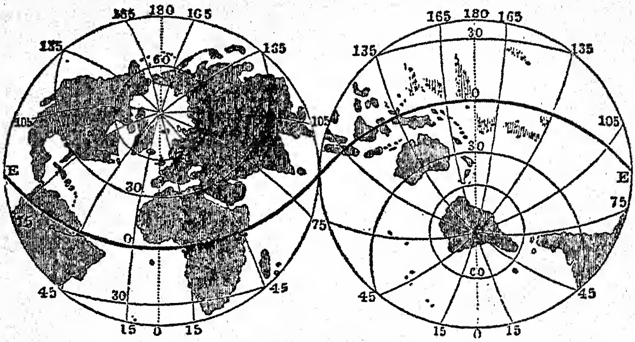


Fig. 10 —DISTRIBUTION OF LAND AND WATER.

the Orient accords with its great breadth; for it averages 6,000 miles from east to west, which is far more than twice the mean breadth of the Occident (2,200 miles). The inequality of the two continental masses has its parallel in the inequality of the Pacific and Atlantic oceans; for the former (6,000 miles broad) is more than double the average breadth of the latter (2,800 miles). The northern portion of the Orient, or Europe and Asia combined, makes one continental area, Eurasia; its general course is east and west. The northern portion of the Occident, North America, is elongated from north to south."

The mean depth of the oceanic depression is about 14,000 feet; and the mean height of the land (according

to Murray) 2,252 feet. The greatest depth reached by soundings (south of the Friendly Islands) is 30,930 feet; the greatest height on the land (Mt. Everest of the Himalayas) is 29,000 feet; hence the interval between the extremes of altitude and depression is over eleven miles. If the continental plateaus and the floor of the ocean were graded to a common level, the ocean would still have a depth of about 10,000 feet. The mean height of Europe is 939 feet; Asia, 3,189 feet; Africa, 2,021 feet; Australia, 805 feet; North America, 1,888 feet; South America, 2,078 feet. The mean depths of the great oceans are: of the North Atlantic, 15,000 feet; North Pacific, 16,000 feet; South Atlantic and South Pacific, and probably the Indian Ocean, about 13,000 feet.

The form of the ocean's bed has been fairly accurately determined. From north to south, along the middle of the Atlantic, there is a wide zigzag ridge or plateau, conforming nearly in trend to the American coast. It lies at a depth of 6,000 to 12,000 feet, while on either side the bottom slopes away to depths mostly between 15,000 and 20,000 feet. In the area of 4,000 fathoms and over, situated north of the island of Puerto Rico, the United States Coast Survey steamer Blake found, in 1883, a depth of 27,366 feet. This greatest depth, and large areas of deep water, exist in the western part of the ocean. In the Pacific Ocean, a shallow area extends, with little interruption, from the Malay Archipelago southeastward beyond the Paumotu Islands, and thence northeastward to the Isthmus of Panama, southeastward to Patagonia, and southward to the Antarctic. The deepest parts of this ocean also are in its western half. One deep area is east of Japan; another, south of the Ladrones; others, near the Friendly Islands. Northward in the northern hemisphere the ocean shallows rapidly. The depth in Bering Strait is not over 150 feet; and between Great Britain and Iceland it does not exceed 6,000 feet, and is mostly under 3,000 feet.

The ocean's bottom has no steep ridges like those of ordinary mountain scenery. But broad elevations exist in some parts, as found in the soundings of the Tuscarora between the Hawaiian Islands and Japan. Besides these, there are many mountain ranges rising somewhat abruptly from the depths, having the islands of the ocean as their summits, which rival in length those of the continents. The Hawaiian range, if the coral islands in the line of the volcanic islands are included, has a length of 2,000 miles; and it rises steeply from depths of 15,000 to 18,000 feet. The mountains of Hawaii have a height above the ocean of nearly 14,000 feet, and a depth of 17,000 feet was found but 50 miles south of the island, thus making the whole height nearly 31,000 feet. The islands of the tropical Pacific make together an island chain about 5,000 miles long; and they are the tops of a mountain chain of this great length.

Along the oceanic borders, the sea is often, for a long distance out, quite shallow, because the continents continue on under water with a nearly level surface; then comes, usually at a depth of about 100 fathoms, or 600 feet, a rather sudden slope to the deep bed of the ocean. This is the case off the eastern coast of the United States, east and south of New England. Off New Jersey the deep water begins along a line about 80 miles from the shore; off Virginia this line is 50 to 60 miles at sea; and thus it gradually approaches the coast to the southward; while to the northward it continues 80 to 100 miles off from the New England coast, and passes far outside of Nova Scotia and Newfoundland. The slope of the bottom for the 80 miles off New Jersey is only 1 foot in 700 feet. The true boundary between the continental plateau and the oceanic depression is the commencement of the abrupt slope. The same abrupt slope near the 100-fathom line exists in the Gulf of Mexico. The British Islands are situated on a submerged portion of the European continent, and are essentially a part of that continent, the

limit of the oceanic basin—the 100-fathom line—being 50 to 100 miles outside of Scotland and Ireland, and extending south around the Bay of Biscay. West of the English Channel the depth increases, in a distance of only ten miles, from 100 fathoms to 2,000. New Guinea in a similar way is proved to be a part of Australia. Such facts occur on most coasts; and they teach that the oceanic depression is generally separated from the continental plateaus by a well-defined outline.

The surface of the continent comprises plains or lowlands, plateaus or table-lands, and mountain ridges. The mountain ridges may rise either from the lowlands or the plateaus. The plateaus are large areas of approximately level surface at an altitude of a thousand feet or more above the sea. They are often parts of the great mountain chains, lying between the ridges, or forming the mountain mass out of which the ridges rise. For example, the regions of northern and southern New York are plateaus (the former averaging 1,500 feet in height, the latter 2,000 feet) situated on the western borders of the Appalachian chain; and the same is true of the Cumberland table-land in Tennessee. Between the Sierra Nevada and the Wasatch, there is a plateau of vast extent, called the Great Basin, having the Great Salt Lake in its northeastern portion; its height above the sea averages 4,000 feet; the Humboldt Mountains and other high ranges rise out of it. It continues northward into British America and southward into Mexico. The eastern part of New Mexico, with the western part of Texas, is a plateau of about the same elevation, called the Llano Estacado. The Desert of Gobi, between the Altai and the Kuen-Lun range, is a desert plateau about 4,000 feet high, while the plateau of Tibet, between the Kuen-Lun range and the Himalayas, is 11,500 to 13,000 feet above the sea. Persia and Armenia constitute another plateau. These examples are sufficient to explain the use of the term.

The continents are constructed on a common model:

they have high borders and a low center, and are, accordingly, basin-shaped. North America has the Appalachians on the eastern border, the Cordillera on the west, and between these the low Mississippi basin.

South America, in a similar manner, has the Andes on the west, the Brazilian Mountains on the east, and other heights along the north, with the low region of the Amazon and La Plata making up the larger part of the great interior. In the Orient there are mountains on the Pacific side, others on the Atlantic; and, again, the Himalayas, on the south, face the Indian Ocean, and the Altai Mountains face the Arctic seas. Between the Himalayas (or rather the Kuen-Lun Mountains, which are just north) and the Altai, lies the plateau of Gobi, which is low compared with the inclosing mountains; and farther west there are the lowlands of the Caspian and Aral, the Caspian lying even below the level of the ocean.

The Urals divide the 6,000 miles of breadth into two parts, and so give Europe some title to its designation, as a separate continent. West of their meridian there are again extensive lowlands over middle and southern European Russia. In Africa there are mountains on the eastern border, and on the western border south of Guinea; there are also the Atlas Mountains along the Mediterranean, and the Kong Mountains along the Guinea coast; and the interior is relatively low, although mostly 1,000 to 2,000 feet in elevation. In Australia, also, there are highlands on the eastern and western borders, and the interior is low. All the continents are, therefore, constructed on the basin-like model.

There is a second great truth with regard to the continental reliefs: the highest border faces the largest ocean. Each of the continents sustains the truth announced. North America has its great mountains, the Cordillera, on the side of the great ocean, the Pacific; and its small mountains, the Appalachians, on the side of the small ocean. South America, also, has its highest border on

the west. The Orient has high ranges of mountains on the east, or the Pacific side, and the lower ranges, as those of Norway and other parts of Europe, on the west; and the Himalayas face the great Indian Ocean, while the smaller Altai range faces the small Northern Ocean. In Africa, the mountains on the side of the Indian Ocean are higher than those on that of the Atlantic. In Australia the highest border is on the Pacific side; for the South Pacific fronting east Australia, is greater than the Indian Ocean fronting west Australia. Hence the basin-like shape before illustrated is that of a basin with one border much higher than the other; and with the highest border on the side of the largest ocean.

The features described have a vast influence in adapting the continents for Man. America has its highest border in the far west, with all its great plains and great rivers inclined toward the Atlantic; for through the Gulf of Mexico the whole interior, as well as the eastern border, has its natural outlet eastward. The Orient, instead of rising into Himalayas on the Atlantic border, has its great heights in the remote east; and its vast plains, even those of Central Asia, have their natural outlet westward, over Europe and through the Mediterranean, or toward the same Atlantic Ocean. Thus, as Professor Guyot has said, "the vast regions of the world, which are best fitted for man, by their climate and productions, are combined into one great arena for the progress of civilization."

CHAPTER VII

STRATA MOVEMENTS AND EARTHQUAKES

DYNAMICAL GEOLOGY investigates the process of change at present in progress upon the earth, whereby modifications are made on the structure and composition of the crust, on the relations between the interior and the surface, as shown by volcanoes, earthquakes, and other terrestrial disturbances, on the distribution of land and sea, on the outlines of the land, on the form and depth of the sea-bottom, on marine currents, and on climate. Bringing together the whole range of geological activities, it leads to precise notions regarding their relations to each other, and the results which they achieve. In other words, the present order of things must be employed as a key by means of which to decipher the hieroglyphics of the past, and proceed from what may be directly observed to past changes which can only be inferred.

"We might assume," says Scott in his 'Introduction to Geology,' "that the present was so radically different from the far-distant past, that the one could throw no light upon the other. Such an assumption, however, would be most illogical, for there is nothing to support it. There is no reason to imagine that physical and chemical laws are different now from what they have always been, and the more we study the earth, the more clearly we perceive that its history is a continuous whole, determined by factors of the same sort as are now continuing to modify it." Some of these forces, however act with greater efficiency at

the present time than they did in the past, others with less.

The dynamical agencies may, primarily, be divided into two classes: (1) the Subterranean Agencies, which act, or at least originate, at considerable depths within the earth; and (2) the Surface or Superficial Agencies, whose action takes place at or near the surface of the earth. The former are due to the inherent energy of the earth, and their seat is primarily subterranean, tho their effects are very frequently apparent at the surface. These agencies are also called 'igneous' (from 'ignis,' fire), which is a misnomer; but the term is nevertheless in common use. The surface agents, including the circulation of the winds and waters, the changes of temperature, and the activities of living beings, all depend upon the sun's energy, and were that withdrawn, only such changes as are brought about by the earth's internal heat could continue in operation.

Some of the agencies that shall be considered may seem, at first sight, to be very trivial in their effects, but it must be remembered that they appear so only because of the short time during which they can be observed. For enormously long periods of time they have been steadily at work, and their cumulative effects must not be left out of account in estimating the forces which have made the earth what it now is.

No human eye has ever witnessed the birth of a mountain range, or has seen the beds of solid rock folded and crumpled like so many sheets of paper, or observed the processes by which a rock is changed in all its essential characteristics; 'metamorphosed,' as it is technically called. Yet these things are continually being accomplished in Nature's workshop. All such problems, however, must be discussed in connection with structural geology.

The logical order of treatment of these subjects is to begin with the subterranean agencies, because the most ancient rocks of the earth's crust were doubtless formed

by these forces, and the circulation of matter upon and through the crust started originally from igneous rocks. These agencies fall naturally into two great groups: Diastrophism, or movements of the earth's crust; and Vulcanism, or the phenomena of volcanoes, geysers, etc.; while a third group, Earthquakes, is intimately associated with each of the others, but on account of its great importance will require separate treatment. Crustal movements to be discussed here may be distinguished as (1) Warping, which is a broad, gentle curving of the surface, upward or downward; (2) Direct Upheaval or Depression, with fracturing and dislocation of the rocks, which may be accompanied by a tilting of the strata. Diastrophic movements of this class are almost, if not quite, invariably associated with earthquakes and can be most conveniently studied in connection with the latter.

Permanent changes of level frequently accompany earthquakes, but these are sudden, and appear to be nearly always the result of dislocation or faulting. By change of level, in the general sense, is meant the gradual elevation or subsidence of land, with reference to the sea, over considerable areas. Such movements are very slow, and hence are apt to escape observation, so that there is much dispute as to the facts and still more as to their interpretation. But there is an abundance of indisputable evidence showing that considerable changes in level have been effected even since the dawn of civilization.

On certain coasts long inhabited by civilized man, ancient structures like quays and bridges, which were built in the water, may now be found high above it. Such changes have been noted in the Mediterranean lands, especially in southern Italy and the island of Crete. The so-called 'Serapeum' at Pozzuoli, near Naples, is a famous and much discussed example of repeated oscillations upward and downward. This structure was built in Roman times, and probably began to sink while still in use, as appears from the two ancient pavements, one above the

other. Three large monolithic columns of marble, about 40 feet high, are still standing erect, and on each of them is a belt about 10 feet above the ground and 9 feet wide,

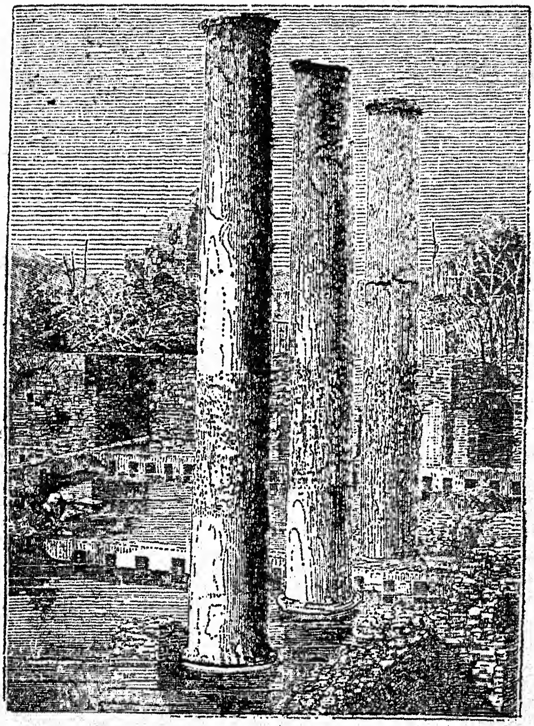


Fig. 11 —Pillars Showing Subsidence and Elevation of Earth's Crust.

honeycombed by the boring mollusk, 'Lithodomus,' which still abounds in the neighboring bay, and many of the shells were actually found in the columns. Evidently, the build-

ing was once submerged to a depth of nearly 20 feet, and when under water the columns were attacked and perforated by the mollusk. Just when the reëlevation began is not definitely known, but it was probably completed in 1538, when a volcanic eruption in the neighborhood resulted in the formation of Monte Nuovo. For nearly a century past a slow movement of subsidence has been going on.

'Raised beaches,' filled with the remains of marine animals, are a decisive proof of a rise of the land, or a fall in the sea, and evidence of a similar kind is given by raised coral reefs. The eastern coast of North America shows marks of relatively late elevation, increasing in amount northward. At the mouth of the Connecticut, the highest beach is 40 to 50 feet above sea-level, at Boston it is 75 to 100 feet, on the coast of Maine it is 200, and on that of Labrador 500 feet. On the eastern shore of Hudson's Bay the marine terraces and beaches extend up to 700 feet above sea-level.

In the geological period (Pleistocene) immediately preceding the recent one, several immense lakes existed in the interior of North America, some around the basins of the present Great Lakes, others in Utah and Nevada. The ancient shore-lines of these vanished lakes may still be seen, for the most part in admirable preservation; when first formed by the action of the waters, these beaches must have been level, but accurate surveys show that they are no longer so, but have undergone extensive warpings.

As ancient structures on long-inhabited coasts sometimes show elevation, they likewise sometimes show depression. On the north coast of Egypt ancient rock-cut tombs are now visible beneath the waters of the Mediterranean. South of Stockholm, in Sweden, the remains of an ancient hut were found in place, 65 feet below the surface, buried in marine deposits which contain shells of the same species now living in the Baltic. On the

west coast of Greenland the sinking is so rapid as to have attracted the attention of the natives.

The sea-bottom south of Long Island must once have been dry land, because a river flowing into the sea cannot excavate the sea-bottom below the level of its mouth. The ancient channel of the Hudson has been traced by soundings out to the edge of the continental platform, more than 100 miles southeast of Sandy Hook. In the same manner the channel of the St. Lawrence may be followed out through the Straits of Belle Isle, and that of the Congo extends out 70 miles from the west coast of Africa, with a depth of nearly 1,000 fathoms.

What are known as earthquakes are caused by rapid vibrations of the earth's crust due to some sudden shock in the earth's interior. The displacements—that is, the amplitude of the vibrations—in the great majority of earthquakes is only a fraction of a millimeter. When it exceeds four or five millimeters the quake is destructive. The greatest destruction is wrought in instances where the buildings are built upon loose foundations or upon "made ground." Steel-framed structures founded upon bed rock do not fall easily, for they vibrate with the rock. Centuries ago the Chinese devised an instrument that detected these vibrations of the earth's crust, for the majority of them can only be detected by instruments. Their device, as have all successful subsequent ones, depended on the inertia of a suspended weight or pendulum. The delicately poised weight alone is unaffected by the vibrations; a paper under it moves with the tremblings of the crust, and a pen held by the pendulum records the movement. In the Chinese device their pendulum merely displaced little bullets which were carefully supported.

Modern instruments, called seismographs, do not only tell when an earthquake has occurred, but they record the tremors, different pendulums recording the various components, horizontal and vertical, of the movements. In the cases of a violent disturbance communication of

all kinds is often cut off, but there are now seismographs in all parts of the world, and by comparing the times at which various instruments recorded similar phases of the shock the center of the disturbance can generally be accurately determined.

Fig. 12 —Earthquake Areas in the Western Hemisphere.

The study of seismographic records has brought to light many highly significant facts, among others that minute and insensible 'tremors' of the earth are almost incessant, but some, at least, of these tremors are due to atmospheric changes, and it is not known how large a proportion of them are of subterranean origin. Another very

important result of the seismographic observations is that when a very distant earthquake is registered, three series of waves are indicated, viz., the 1st and 2d phases of the preliminary tremors, and the larger waves of the main shock. Those first to arrive, called the preliminary tre-

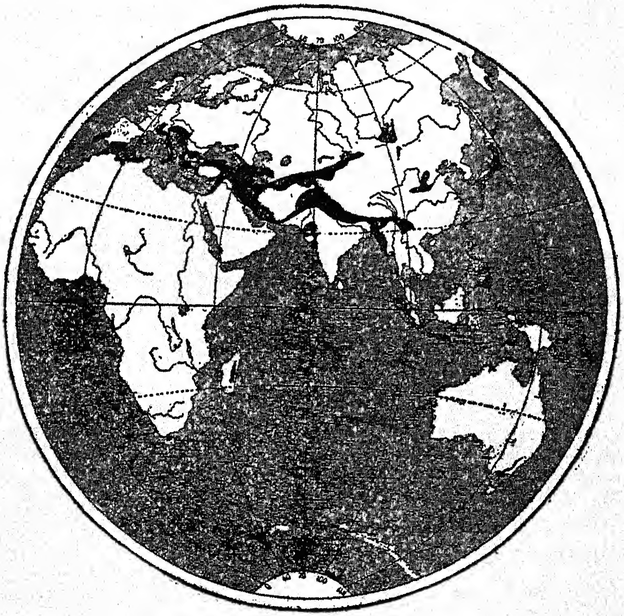


Fig. 13 —Earthquake Areas in the Eastern Hemisphere.

mors, are believed to be transmitted through the mass of earth along the chord of the arc included between the point of origin and the point of observation. The waves of the third series are longer and slower—*i.e.*, of greater amplitude and period—and constitute the "main shock"; they are believed to follow the curvature of the earth.

Sensible earthquakes are numerous, not less than 30,000 being the estimated number per annum; of course, the great majority of these are very light. It would be just to say that the crust quivers constantly. While any part of the earth's surface may be visited by earthquakes, there is a very great difference between different regions in regard to their seismicity—*i.e.*, the frequency and violence of the shocks which affect them. The main seismic regions, when platted upon a map, are found to be arranged in two great-circle belts, one of which encloses the Pacific Ocean and the other girdles the whole earth. The latter includes the Mediterranean region, the Azores, the bed of the Atlantic westward from the Azores to the West Indies, those islands themselves, Central America, Hawaii, Japan, China, India, Afghanistan, Persia, and Asia Minor.

Altho earthquakes are commonly perceptible upon the land, the most frequent seats of disturbance are in the bed of the sea. In the sea there are regions quite free from quakes and others of a high degree of seismicity, but quakes also occur in an isolated and scattered manner. Submarine cables are frequently interrupted at the same points. Thus the cable from the Lipari Islands to Sicily has been broken five times at the same point.

A great earthquake usually begins suddenly and without warning. A rumbling sound, quickly becoming a loud roar, accompanies or slightly precedes the movement of the ground, which is at first a trembling, then a shaking, and finally a rapid swaying, wriggling motion, describing a figure 8, which is extremely destructive and overthrows the buildings affected, and even in the open country it is impossible to keep one's feet. The surface of the ground has been repeatedly observed to rise in low, very swiftly moving waves, somewhat like those on the surface of water, upon the crests of which the soil opens in cracks, closing again in the wave-troughs. When the earth-waves traverse a forested region, the trees sway violently from side to

side, like a field of ripe grain in the breeze. In the details of movement earthquakes differ greatly from one another; sudden and extremely violent vertical shocks may come from below, or the surface may writhe and twist in every direction, instead of rolling in waves; there may be only a single shock, or many successive ones.

Strictly speaking, the geological effects of earthquakes are of less importance than is usually supposed. The violent shaking of the surface often brings about great landslips in mountain regions, which precipitate enormous masses of earth and rock from the heights down into the

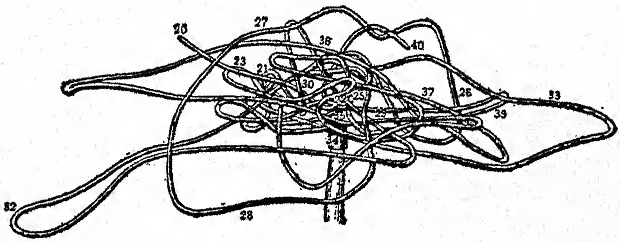


Fig. 14 —Model of Movements of Surface of Earth Between 20th and 40th Second of an Earthquake Shock. (Omori.)

valleys. In all of the more violent quakes cracks and fissures of the ground are formed, which may close again or remain open, and may show a lineal, curved, zigzag, or radiating arrangement. Through these fissures great quantities of water and sand are often forced up from below and form little sand craters, or water-filled funnels on the surface. Frequently the fissures assume the character of 'faults,' or dislocations, one side being raised, the other depressed, so that long 'scarps,' or low cliffs, are left standing. In the San Francisco earthquake of 1906 two long lines of parallel faults were formed, with varying throw up to twenty feet.

A very common result of earthquakes is a change in the

circulation of underground waters. Wells and springs go dry, while other springs are formed in new places, or old ones may be increased in volume. The changes in the form of the land surface produce corresponding changes in surface drainage; rivers are diverted into new channels or dammed into lakes, while streams intersected by fault-scarps form new cascades.

The great earthquake which occurred at the extremity of the Italian peninsula near Messina, in 1908, was at first

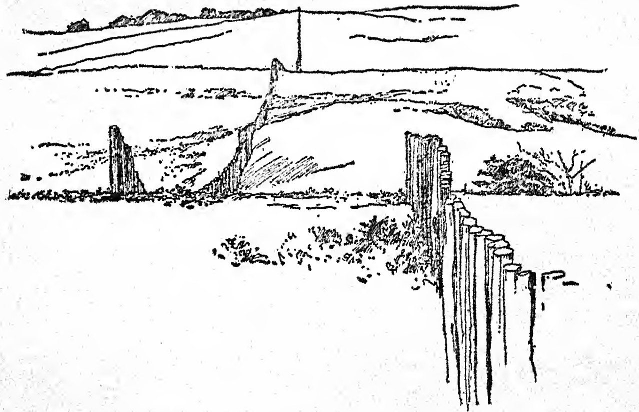


FIG. 15—FENCE BROKEN AND SHIFTED HORIZONTALLY IN THE SAN FRANCISCO EARTHQUAKE OF 1906. (*Scott.*)

seismologically explained as the propagated effect of a fault-slip. It was not the eruptive outburst of Etna, according to Sir Norman Lockyer, that set the earth quivering, but a prolonged tension of the crust, a sudden snap, an abrupt settlement, and then the waves of the quake. The celebrated geologist, Professor Edward Suess, of Vienna, expressed himself very pessimistically regarding the outlook. According to his theory, the constant Calabrian and Sicilian shocks do not result from volcanic out-

breaks anywhere, but are occasioned by a "general sinking." A series of shocks which culminated in May, 1914, showed the general seismic unrest of the district.

In studying the causes of earthquakes in general, they are usually divided into two classes, 'volcanic' and 'tectonic,' tho it is often impossible to determine to which of the two classes a given earthquake should be referred. The volcanic earthquakes, which are closely associated in time and space with volcanic eruptions, are due to steam explosions and to the struggles of the rising lava within the earth to escape. Tectonic earthquakes are held to be due to stresses in the interior of the earth, which, when suddenly yielded to by the rocks, cause the jar and shock which generates the earthquake. No entirely satisfactory hypothesis has been advanced to account for the origin of the stresses referred to above. The explanation usually accepted is that the earth is slowly contracting on account of the loss of heat, and that the crust, which must follow the shrinking interior, is being crowded into a smaller space, with resultant ruptures and shocks. On the other hand, it is contended by some geologists that all earthquakes are essentially volcanic in origin. The stresses induced by the changing of the earth's axis also have been put forward as an explanation.

Dr. T. J. J. See, of the naval observatory on Mare Island, was the foremost of the authorities who declared that the Messina earthquake was caused by the explosive force of steam generated by the percolation of sea water to the molten or red hot rocks far below the earth's surface. He asserted that the so-called waves following great earthquakes are not really "tidal." He affirmed that they are produced by seismic disturbances of the sea bottom, and should be called "seismic sea waves."

A seismic wave, explained Dr. See, is due to a sinking of the sea bottom at some distance from the shore. When this happens, the water flows in from all sides to fill in the depression. Then, when the currents meet at the cen-

ter and raise a ridge by their mutual impact, the ridge collapses under gravity and sends the first great wave ashore. "Where the ridge of water once was," he wrote, "a second depression in the sea-level is thus developed; the water again flows as in the first case, and the process keeps on repeating itself.

"On June 15, 1896, the northern shores of Japan were visited by terrible earthquake shocks, which were recorded on seismographs in Europe. The disturbance originated beneath the Tuscarora Deep. This oceanic abyss, which reaches a depth of forty-six hundred fathoms, or more than twenty-seven thousand feet, is known as the worst earthquake region in the world. On the Japanese coast, as on that of South America, the water first withdrew from the shore, and later returned in a great wave. Along a region seventy miles in length the coast villages were washed away, and 30,000 people perished from the earthquake and the inundation.

"In other instances the water rises suddenly, overflows the coast, and washes ships inland, without any previous withdrawal from the shore. For instance, on December 29, 1854, the city of Simoda, in Japan, was overwhelmed by a sudden inrush of the sea about an hour after a violent earthquake. Seismic waves of this class are prdouced by an upheaval of the sea bottom, which lifts the overlying water bodily upward, causing it to rush in upon the shore."

In summing up, Dr. See said that "the so-called 'tidal waves' that follow violent earthquake shocks are due either to the sinking or to the elevation of the sea bottom, and that earthquakes themselves are due to the secular leakage of the ocean bottoms."

The great depth and the enormous pressure of the sea water, with the aid of capillary forces, drive it through the rock crust of the earth till it comes to the intensely hot strata some twenty miles below the surface. The earth in many places is at a high temperature inside, and steam develops under the crust. When the pressure of the

Viscous Lava Spine of Mt. Pelée, Martinique.
A unique volcanic phenomenon. (Courtesy of E. O. Hovey.)

steam accumulates, it finally shakes the solid crust until it gets relief through some opening.

Practical people, notably insurance companies, are asking the scientists whether seismic disturbances have not a common and determinable origin and if their cause can be ascertained if they will ever be able to foretell their occurrence. It has been noted that some thirty thousand shocks are detected annually by the recording instruments. Of all these only sixty are "world-shaking" and observable from a distance. The two rings which the earthquake districts make when plotted on the globe also have been referred to. Professor Milne and others attach peculiar significance to this geographical distribution.

Now, this is not merely a convenient geographical summary, but a physical fact of vital importance, according to recent researches by Professor Jeans. In a remarkable paper read before the Royal Society he gave reasons for believing that the earth is not so absolutely a sphere or spheroid, but is slightly of pear-shape. Under gravitational stress it is continually approaching the spheroidal form—the pear is being crushed into a sphere by its own attraction; and the result is a series of earthquakes which will naturally occur in the weakest places.

In 1912 Professor Davison pointed out that the tectonic strains are intermittent and that it is a misinterpretation of the seismological facts to try and force them to fit any one theory. He declared that probably all the factors known were operating together, many of them neutralizing, and that the cause of the sudden slip came with the arrival of a point of accumulated stresses when the frictional resistance and inertia of rock masses was overcome.

For many years it has been observed that there are slight but irregular changes in latitude, or, in other words, the axis of the earth does not always point in the same direction. The world top is not spinning truly, but it wobbles slightly. When the change in direction of its

axis is sharp, large earthquakes have been frequent. If a swiftly moving body is, so to speak, compelled to turn a corner, that it should be subjected to strains which might result in yielding, is easily conceivable.

A shifting of the earth's axis, even to the slightest degree, would impose a great strain upon some parts of the earth's crusts, and this might explain earthquakes and in turn lead to appreciable results in foretelling them, but, to use the words of Professor Simon Newcomb, "earthquakes are due to a shifting of the earth's strata, but what causes that shifting is not positively known." The general theory hitherto has been that the shifting is due to the gradual lessening of the earth's surface. The great prestige of Sir Norman Lockyer's name has been given to the Milne theory—that is, that the earthquake is a natural phenomenon resulting from the failure of the earth to swing true upon its axis.

The great seismic disturbances of the past few years tend, this expert thinks, to support the theory advanced by Professor Milne. This would yield the inference that it is possible to calculate the frequency of earthquakes in the light of their suspected cause. "However much announcements of this nature may appeal to the scientific mind," says Professor Milne, "the layman requires something more definite—if not to the minute he would at least like to know the day on which an earthquake is to occur."

The science of seismology may never become so precise as all that, but when the factor of causation is given, when it is known for certain whether or not the sun spots or the shrinkage of the globe or the alteration of the direction of the earth's axis must be given credit for the earthquake, the chief problem of the seismological prophet will have been practically solved.

CHAPTER VIII

VOLCANOES AND GEYSERS

A VOLCANO is usually a conical mountain or hill, with an opening, or crater, through which various solid, molten, or gaseous materials are ejected. The essential part of the volcano is the opening, or vent, and some volcanoes consists of almost nothing else. It is known that at least a part of the interior of the earth at a certain depth is hot and that a great part of it is actually or potentially molten. Thus a volcano might be considered as a connection between the interior and the surface, or as a chimney over an especially active part of the interior.

The number of volcanoes now active may be estimated at about 328, of which rather more than one-third are situated in the continents and the remainder on islands. The active volcanoes are not scattered haphazard over the surface of the globe, but are arranged in belts or lines, which bear a definite relation to the great topographical features of the earth as well as to the seismic belts. Two of these belts together encircle the Pacific Ocean. A third band occupies a ridge in the eastern bed of the Atlantic, from Iceland to beyond St. Helena, from which arise numerous volcanic islands and submarine vents.

The phenomena displayed by different volcanoes, or even by the same volcano at different times, vary greatly. It often seems difficult to believe that similar forces are involved, and that the divergences are due merely to different circumstances attending the outbreak. A careful com-

parison, however, of the varying phenomena brings to light a fundamental likeness in them all. Some vents, like Stromboli in the Mediterranean, are in an almost continual state of eruption of a quiet kind; others, like Vesuvius, have long periods of dormancy, broken by eruptions of terrible violence.

The first recorded eruption of Vesuvius, which occurred in 79 A.D. and is described in two letters written to Tacitus by the younger Pliny, was of the explosive type. In this frightful paroxysm little or no molten lava was ejected, but so enormous was the quantity of ashes that at Misenum, across the bay of Naples, the sun was darkened, as Pliny reports, "not as on a moonless, cloudy night, but as when the light is extinguished in a closed room. . . . In order not to be covered by the falling ashes and crushed by their weight, it was necessary to rise often and shake them off."

The explosive type of eruption is exhibited in its extreme form by several of the East Indian volcanoes, and preëminently by Krakatoa, the eruption of which in 1883 was the most frightful ever recorded. This volcanic island, situated in the Strait of Sunda, was little known, except that it had been in eruption in 1680. The catastrophe occurred in August, when, besides the fearful devastation caused by the disturbances of the sea on the coasts of Sumatra and Java, the island itself was almost annihilated.

The force of the explosion produced waves in the atmosphere which were propagated around the whole earth, and the first one was observed in Berlin ten hours after the explosion. The ejected materials were all fragmentary and of an incredible volume; ashes were distributed over an area of 300,000 square miles, the greater part falling within a radius of eight miles around the island; stretches of water that had had an average depth of 117 feet were so filled up as to be no longer navigable. Enormous masses of pumice floated upon the sea and stopped naviga-

tion except for powerful steamers. The flaming-red sunsets which characterized the autumn and winter of 1883-1884 have been very generally ascribed to the refractive effects of the impalpably fine Krakatoa dust.

The islands of St. Vincent and Martinique in the Lesser Antilles were devastated by a series of fearful and nearly simultaneous eruptions, which in certain important respects differ from those of any other known volcanoes. The volcano of St. Vincent, known as La Soufrière, began breaking out on May 6, 1902, in a series of tremendous steam explosions; May 7 the eruption became continuous and on the same day occurred the dreadful, descending "hot blast," a cloud of superheated steam and other gases, mingled with red-hot particles of ash, which rushed down the mountain and destroyed 1,400 human lives. The eruptions, which were repeated at varying intervals and with different degrees of violence for considerably more than a year, were characterized by the absence of lava and by the vast quantity of finely divided ash ejected by the explosions.

The eruptions of Mont Pelée in Martinique were actually less violent, but far more destructive to life than those of St. Vincent. On May 2 the ejections of ash became frequent, increasing until the 8th, when a descending cloud of hot vapors and glowing ash swept with terrible velocity down the ravine of the Rivière Blanche upon the city of St. Pierre, which, together with its 30,000 inhabitants, was instantly annihilated. The velocity of the air set in motion by the descending cloud was sufficiently great to hurl from its pedestal the great iron statue of Notre Dame de la Garde, weighing several tons, to a distance of more than 40 feet.

It is the descending clouds which lend such an exceptional character to the eruptions of St. Vincent and Martinique, but Mont Pelée also displayed certain other peculiar phenomena. While no lava streams were produced, very stiff and viscous lava appeared at the summit,

filling up the old crater and forming a steep cone, through which protruded a lofty obelisk or spine, which, thrust up from below, grew irregularly in height, as it continually lost material by scaling off the top and sides; eventually it fell altogether.

In all eruptions of the explosive kind, a few typical examples of which are described above, the active agency is obviously exploding masses of intensely heated and compressed steam, and all such eruptions are accompanied by gigantic steam-clouds, which, condensing in the atmosphere, fall in rains of torrential volume and violence. The hot water thus produced mingles with the volcanic ash in the air and on the ground, forming streams of hot mud, which are often more destructive than the lava flows themselves. When cold, the mud sets into quite a firm rock, called 'tuff.'

The opposite extreme of volcanic activity from the explosive type is to be found in the volcanoes of the Sandwich Islands, such as Mauna Loa and Kilauea. Here the eruptions are usually not heralded by earthquakes; the lava is remarkably fluid and simply wells up over the sides of the crater, pouring down the sides of the mountain in streams which flow for many miles. More commonly the walls of the crater are unable to withstand the enormous pressure of the lava column, and the molten mass breaks through at some level below the crater, rising through the fissure in giant fountains, sometimes 1,000 feet high. Even in the ordinary activity of Kilauea jets of 30 and 40 feet in height are thrown up. Hardly any ashes or other fragmental products are formed; and tho the clouds of steam, the invariable accompaniments of volcanic outbursts, are present, yet the quantity of steam is relatively less than in those volcanoes in which explosions occur.

Between such extremes as the Hawaiian volcanoes on the one hand and the explosive East Indian type (Krakatoa) on the other may be found every intermediate gradation. Thus, tho occasionally breaking out with violence,

Stromboli has been in a state of almost continuous activity for more than 2,000 years, and is, for long periods, in such exact equilibrium, that barometric changes have a marked effect upon its activity and the Mediterranean sailors make use of it as a weather signal.

Evidently one active agent in these phenomena is imprisoned steam in its struggles to escape. Different as are the manifestations at various volcanoes, steam is an important cause of the eruption in all cases, tho the conditions under which it acts vary widely.

In the modern eruptions of Vesuvius essentially the same phenomena may be observed, but on a far grander and more terrible scale. Earthquakes usually announce the coming eruption, increasing in force until the outbreak occurs. Terrific explosions blow out fragments of all sizes, from great blocks to the finest and most impalpable dust. Inconceivable quantities of steam are given off with a loud roar, which is awe-inspiring in its great and steady volume.

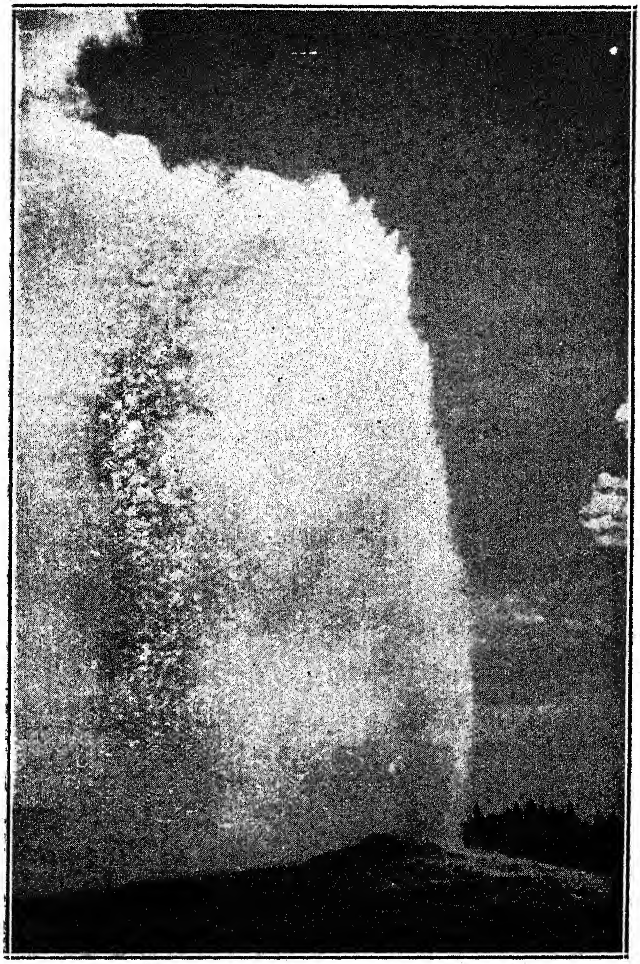
A volcano, as its activity wanes, may pass into the Solfataric stage, when only volatile emanations are discharged. The well-known Solfatara near Naples, since its last eruption in 1198, has constantly discharged steam and sulphurous vapors. The island of Vulcano has now passed also into this phase, tho giving vent to occasional explosions. As the result of solfataric action, masses of rock are decomposed below the surface and new deposits of alum, sulphur, sulphides of iron and copper, and layers of silica, etc., are formed above them. The 'lagoons' of Tuscany are basins into which the waters from soffioni are discharged, and where a precipitation of their dissolved salts takes place. Among the substances thus deposited are gypsum, sulphur, silica, and various alkaline salts; but the most important is boracic acid, the extraction of which constitutes a thriving industry.

Another class of gaseous emanations betokens a condition of volcanic activity further advanced toward final extinction. In these the gas is carbon-dioxide, either issu-

ing directly from the rock or bubbling up with water which is often quite cold. The famous Valley of Death in Java contains one of the most remarkable gas-springs in the world. It is a deep, bosky hollow, from one small space on the bottom of which carbon-dioxide issues so copiously as to form the lower stratum of the atmosphere. Tigers, deer, and wild-boar, enticed by the shelter of the spot, descend and are speedily suffocated. Many skeletons, including those of man himself, have been observed. "Death Gulch" is the significant name given to another example of the accumulation of carbonic acid in Western America.

Eruptive fountains of hot water and steam, to which the general name of Geysers—*i.e.,* gushers—is given, from the examples in Iceland, which were the first to be seen and described, mark a declining phase of volcanic activity. Iceland has long been famous for its geysers, and a very beautiful series in New Zealand was destroyed by the volcanic eruption in 1886. But probably the most striking and numerous assemblage is that which has been brought to light in the "Yellowstone National Park." In this singular region the ground in certain tracts is honeycombed with passages which communicate with the surface by hundreds of openings, whence boiling water and steam are emitted. In most cases the water remains clear, tranquil, and of a deep green-blue tint, tho many of the otherwise quiet pools are marked by patches of rapid ebullition. These pools lie on mounds or sheets of sinter and are usually edged round with a raised rim of the same substance, often beautifully fretted and streaked with brilliant colors. The eruptive openings usually appear on small, low, conical elevations of sinter, from each of which one or more tubular projections rise. It is from these irregular tube-like excrescences that the eruptions take place. The term geyser is restricted to active openings whence columns of hot water and steam are from time to time ejected; the non-eruptive pools are only hot springs.

In the Upper Fire Hole basin of the Yellowstone Park



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'OLD FAITHFUL' GEYSER, YELLOWSTONE PARK.

one of the geysers, named 'Old Faithful,' ever since the discovery of the region has sent out a column of mingled water and steam every sixty-three minutes or thereabouts. The column rushes up with a loud roar to a height of more than 100 feet, the whole eruption not occupying more than about five or six minutes. The other geysers of the same district are more capricious in their movements, and some of them more stupendous in the volume of their discharge. The eruptions of the 'Castle,' 'Giant,' and 'Beehive' vents are marvelously impressive.

The action of geysers is due to the condition that subterranean waters have access to hot rocks (as the interior

Fig. 16 —Geysers Forced Up Through Oblique Strata.

of great lava sheets, retaining a high temperature on account of the poor conductivity of the material), and that the conduit communicating with the surface is so narrow that convection currents cannot be freely established. The heat accordingly increases in the deeper part of the column of water, until steam is formed, by whose expansion the cooler waters above are explosively ejected. After an eruption the water flows back into the underground passages and gradually becomes heated up for another explosion.

Heated waters act on the rocks with which they are in contact and decompose them, and, as most rocks—especially volcanic rocks—contain some kind of feldspar, the waters become slightly alkaline through the alkali of the

feldspar, and so are enabled to take up silica and make siliceous solutions. The silica taken into solution is deposited again around the geyser in many beautiful forms and makes the bowl or crater from which the waters are thrown out.

From a geological point of view the products of volcanic action form a most important part of the subject, because they contribute largely to the permanent materials of the earth's crust. Volcanic products are of three kinds: (1) Lava, or molten rock; (2) fragmental material, including blocks, lapilli, bombs, the so-called volcanic ashes, cinders, and the like; (3) gases and vapors.

A lava is a more or less completely melted rock; the degree of fluidity varies greatly in different lavas, but is rarely if ever perfect. The degree of fluidity depends upon several factors, the most obvious of which is temperature; the more highly heated the mass is, the more perfectly will it be melted. The quantity of imprisoned gases and vapors present has also an important effect, and some lavas appear to owe nearly all their mobility to these vapors. A third and most significant factor is the chemical composition. Those lavas which contain high percentages of silica, the acid lavas, are much less readily fusible than the basic lavas, in which the percentage of silica is lower.

When a lava stream reaches the surface of the ground, the imprisoned vapors immediately begin to escape and the surface of the molten mass to cool and harden. The surface layers are blown by the steam bubbles into a light, frothy or slaggy consistency, forming "scoriæ" or cindery masses. The motion of the lava breaks up this thin crust into loose slabs and blocks, and on the advancing front of the stream these loose masses rattle down over one another in the wildest confusion. The front of a lava stream advances, not by gliding over the ground, but by rolling, the bottom being retarded by the friction of the ground and the top moving faster, so that it is continually rolling down at the curved front end and forming the bottom. Ordinarily

the motion soon becomes very slow, tho thoroly melted masses pouring down steep slopes may, for a short time, move very swiftly. One of the lava floods from Mauna Loa moved fifteen miles in two hours, and for shorter distances much higher rates of speed have been observed; but this is very exceptional.

When lava cools rapidly, it solidifies as a glass—obsidian or tachylite. When it cools slowly, it forms a truly crystalline rock. Between the extremes are various gradations. If the swiftly cooling portions have been much disturbed by the bubbles of steam and vapors, they are made light and frothy; in some cases, as in pumice, they will float upon water. The lavas which contain large crystals embedded in a fine stony or glassy base are said be of a 'porphyritic texture.' A mass of lava, when it cools and solidifies, necessarily contracts, and since the cohesion of the mass is insufficient to allow it to contract as a whole, it must crack into blocks, separated by fine crevices, which are called joints.

Not all the lava produced in and around a volcanic vent can reach the surface. Some of it may be forced horizontally between beds of the surrounding rocks, thus forming intrusive sheets, which, when exposed in sections, may be readily distinguished from surface flows by the fact that they have consolidated under pressure, and hence have no slag or scoriæ associated with them. Other portions of the lava will fill up vertical fissures in the volcanic cone or in the underlying rocks, and, solidifying in these fissures, form 'dykes.' Such a fissure, twelve miles in length and filled with molten lava, was observed by Sir Charles Lyell in the neighborhood of Etna.

The division of fragmental products includes all the materials which are ejected from the volcano in a solid state. These are of all sizes and shapes, from huge blocks weighing many tons, down to the most impalpable dust, which the wind will carry for thousands of miles. The more violently explosive the eruption, the greater the pro-

portion of the lava that will be blown into fragments. In such eruptions as that of Krakatoa, all of it is thus dispersed and none remains to form lava flows. Cindery fragments thrown out of the vent are called 'scoriæ,' while portions of still liquid lava thus ejected will, on account of their rapid rotation, take on a spheroidal form and are called 'volcanic bombs.' 'Lapilli' are smaller, rounded fragments, and 'volcanic ash' and 'dust' are very fine particles, tho with a wide range of variation in size. The term 'ash' is so far unfortunate that it implies combustion, but nevertheless it accurately describes the appearance of these masses.

In the immediate neighborhood of the vent fragments of all sizes accumulate, but the farther from the volcano, the smaller do the fragments become. The coarser masses around the vent form a 'volcanic agglomerate,' in which the fragments are of all shapes and sizes, heaped together without any arrangement. More regular sheets of large angular fragments form 'volcanic breccia,' and these may be seen on a grand scale in the Yellowstone National Park and in many other parts of the Rocky Mountain region. The finer accumulations of ash, formed at a greater distance from the vent, are roughly sorted by the air and often quite distinctly divided into layers, while, as already explained, the muds on drying set into quite a firm rock, called 'tuff' or 'tufa.'

It is important to emphasize the vast quantity of material which, in many volcanic eruptions, is brought from the interior of the earth and deposited on the surface. Thus the eruption of Skaptar Jokul in Iceland, in 1783, produced an amount of lava which is calculated as exceeding six cubic miles in volume. The fragmental materials derived from the great explosion of Krakatoa, in 1883, are estimated at 4.3 cubic miles, while for that of Temboro, in 1815, Verbeek gives the almost incredible figures of 28.6 cubic miles.

As the ejections flow off or fall more or less symmetri-

cally around the vent, the form of a volcanic peak necessarily tends to become conical.

The cone of Vesuvius consists mostly of cinders, and is accordingly steep, nearly 40°. Etna, about 10,000 feet high, and Mauna Loa in Hawaii, nearly 14,000 feet, consisting of lava streams, have an average slope of less than 10°. A tufa cone is midway between these two extremes.

From the days when Werner and his followers declared volcanic action to be caused by subterranean beds of inflammable material taking fire, speculation has been constant as to the underlying reasons that promote the heat expressed by volcanoes. The contraction of the earth in consequence of its secular cooling was the conception that met with the greatest favor, especially since Cordier calculated that were the earth to contract one millimeter, or one-twenty-fifth of an inch, it would suffice to cause 500 eruptions, each ejecting 1,300,000,000 cubic yards of lava.

By common consent geologists have recognised that the source of volcanic energy must be sought in the high temperature of the interior of the globe. They agree that the main proximate cause of the ordinary phase of eruptivity marked by the copious evolution of steam and the abundant production of dust, slags and cinders from one or more local vents, is obviously the expansive force exerted by vapors dissolved in the molten magma from which lavas proceed. Whether and to what extent these vapors are parts of the aboriginal constitution of the earth's interior, or are derived by descent from the surface, is, however, a question on which opinions differ.

Professor Tschermak and others have been led to conclude that the gaseous ejections are essentially portions of the original constitution of the magma of the globe, and that to their escape the activity of volcanic vents is due.

On the other hand, since so large a proportion of the vapor of active volcanoes consists of steam, many geolo-

gists have urged that this steam has in great measure been supplied by the descent of water from above ground, as it percolates down cracks and joints and infiltrates through the very pores of the rocks.

It appears to be probable that, somewhat like the reservoirs in which hot water and steam accumulate under geysers, the subterranean magma receives a constant influx of water from the surface, which cannot escape by other channels, but is absorbed by the internal magma at an enormously high temperature and under vast pressure. In the course of time the materials filling up a volcanic chimney are unable to withstand the upward expansion of this imprisoned vapor or water-substance, so that, after some premonitory rumblings, the whole opposing mass is blown out and the vapor escapes in the well-known masses of cloud. Meanwhile the removal of the overlying column relieves the pressure on the lava underneath, saturated with vapors or superheated water. This lava therefore begins to rise in the funnel until it forces its way through some weak part of the cone or pours over the top of the crater.

An obvious objection to this explanation is the difficulty of conceiving that water should descend at all against the expansive force within. But Daubrée's experiments have shown that, owing to capillarity, water may permeate rocks against a high counter-pressure of steam on the further side, and that so long as the water is supplied, whether by minute fissures or through pores of the rocks, it may, under pressure of its own superincumbent column, make its way into highly heated regions.

The great physicist, Professor Arrhenius of Stockholm, has done much to clarify the views superincumbent upon modern investigation. Pointing out the amazing potency of force possessed by water-vapor at a temperature far above the critical point, he notes that the magma is charged with this and compares the explosive discharge of lava

and viscous matter in volcanic vents to the ascent of water in a geyser.

At a depth of 540 meters the vapor in the magma must press upward through the molten mass in gas bubbles, and as it escapes the column of liquid is forced upward, sometimes even with explosive violence. At the end of the eruption all the water in the lava column must again be in equilibrium down to that depth, and if no other agency intervened the molten rock would gradually cool and stiffen, so that no further discharge would take place in that funnel. But observation shows that eruptions may continue constant at the same spot for centuries and, as at Stromboli, may be as frequent as those of geysers.

The gaseous water above the critical temperature, in consequence of the enormous pressure (1,000 atmospheres at 10,000 meters down) beneath the surface, may have the same density as liquid water, probably rather less, and will press into the magma. The investigations of recent years have shown, moreover, that superheated subterranean water possesses entirely different properties from those above ground. At about 300° it is estimated that water and silicic acid are about equally strong, but that at 1,000° water is some eighty times and at 2,000° about three hundred times stronger than that acid.

It is a common error to criticize the inability of geologists to explain these matters, and the inexpert reader is very apt to declare that all that is necessary to be known is the nature of the interior of the earth and all the phenomena of vulcanism will arrange themselves in due sequence. In this the casual observer is right, but he forgets that a cognition of the interior of the earth in the present state of scientific investigation is so far impossible. The deepest boring ever made is less than one-three-hundredth part of the earth's radius, and this was in the form of a hole a few inches in diameter.

To give an illustration which may show the cause of the little knowledge of the earth's interior. Suppose the

smallest insect visible to the human eye to be resting on the surface of an orange, and suppose this tiny insect again to be possessed of a boring instrument like the mechanisms of Man, only of course comparable to its own size; that is to say, microscopic to the eye of Man. If this insect should force this tiny borer into the orange, it would not penetrate the outer orange-colored skin of the fruit, much less would it reach the white rind within, while the pulp beneath the rind would forever be distant from its mental grasp. If, however, some inner stress in the orange should cause a fissure, through which the juice within should ooze out, in what manner could the insect (supposing it possessed of equivalent mental powers with Man) explain the emission of the juice from its knowledge of the orange-colored cuticle of the fruit? In similar wise the geologist of to-day is in no position to declare the nature of the interior of the earth from the slight scratchings that have been made upon the surface of the earth by such means as mines, wells and so-called deep borings. He has not even reached the rind, much less the pulp within.

From observations with the pendulum and plumb-line it is calculated that the specific gravity of the earth as a whole is 5.6, while the average specific gravity of the rocks which form the accessible parts of the crust is only 2.6. It follows that the interior of the globe is composed of much denser materials than the superficial portion, and this fact, together with the phenomena of terrestrial magnetism, has led many to the belief that the earth is substantially a globe of some dense substance, such as iron.

Volcanoes, which eject molten and white-hot lavas, and thermal springs, which pour out floods of hot and even boiling water, indicate that the interior of the earth is highly heated, at least along certain lines. But this only reveals a strata of intense heat and does not prove the heat of the entire interior.

It has long been known that after passing through a

zone of variable temperature the heat increases with the depth below the surface. In New York the rate is 1° F. for every 50 feet and in Prussia, where the deepest borings have been made, it is 1° F. for every 60 feet of descent. Should this rate be continued regularly, it would reach, at a depth of 35 miles, a heat sufficient to melt almost any known rock at atmospheric pressure. Yet a depth of 35 miles in comparison with the diameter of the earth is almost a negligible quantity.

Opinions concerning the internal constitution of the earth differ very radically and only within the last few years has evidence begun to accumulate which permits the drawing of certain inferences with a considerable degree of probability. Many hypotheses as to the condition of the earth's interior have been proposed, of which the following are the most important: (1) That the earth is a molten globe, covered only by a relatively thin crust. (2) That it is substantially a solid body. (3) That the interior passes gradually from a solid crust to a gaseous core, heated beyond the critical temperature and yet under such enormous pressure that the core is as rigid as a solid body, but still a gas in molecular condition. According to this theory, the temperature of the earth at the center is about 180,000° F. and the pressure 3,000,000 atmospheres. (4) That it has a very large solid nucleus surrounded by a layer of fused material, upon which the crust floats in equilibrium.

William B. Scott deals with these hypotheses as follows:

"(1) The first, or "thin crust" hypothesis, is now almost entirely abandoned, for there is really no evidence in its favor and very much against it. The velocity and character of the earthquake waves and the astronomical relations of the earth as a planet, especially the tidal phenomena, are strongly opposed to this view.

"(2) That the earth is substantially a solid body is the opinion held at present by many geologists and astronomers. In support of it may be cited the astronomical evi-

dence just mentioned, and the earthquake waves, the speed of which requires a medium more rigid than steel, while the very transmission of the transverse or distortional waves would seem to require a solid medium.

"(3) Between the second and third hypotheses the distinction is one not easy to explain in an elementary manner, and there are many modifications of the latter. According to Arrhenius, "the rigidity of the earth is greater rather than less than that of steel, but the interior forms an extremely viscous mass, with qualities somewhat like those of asphalt at a low temperature, of pitch, sealing-wax and glass." These bodies behave under forces of deformation, which act quickly or with constantly changing direction, like solids; but under slow, long-continued pressures, acting in a constant direction, they behave like fluids. Observations and records of very distant earthquakes show that when the path of the mass-waves penetrates to a depth of more than three-fifths of the earth's radius, the transverse waves of distortion are either extinguished or greatly retarded. This points to a change in the character of the medium and decidedly supports the notion of a gaseous core postulated by this hypothesis.

"(4) The fourth hypothesis, which assumes the presence of a fused layer between the crust and the solid nucleus, with gradual transitions from one to the other, is believed to avoid the astronomical objections to a molten globe, as well as certain geological difficulties in accepting the hypothesis of an entirely solid earth. The earthquake observations, so frequently cited, are decidedly opposed to the belief that a layer of actually fused matter can exist at a moderate depth below the surface.

"It is thus probable that below the superficial crust, only a few miles in thickness, the great mass of the earth is composed of very dense material, which transmits elastic waves like a very perfectly elastic solid, and yet is so highly heated and under such enormous pressure that it is potentially fused and liquefies upon sufficient release of

pressure, and yields plastically to slow, long-continued stresses which act in a constant direction. Furthermore, there is evidence that a core, two-fifths of the earth's diameter and composed of matter in a different state of aggregation, which may be gaseous, occupies the center."

In summing up volcanic activity, then, it may be said that a volcano is a pipe reaching far down into the ground, toward the fluidable stratum underneath the outer crust. The pressure of the overlying rocks prevents this fluidable rock becoming fluid; but if a fissure be opened—such as the vent of a volcano—the overheated fluidable rock will rise until the pressure is so reduced that it can become molten and discharged as lava.

If the fluidable rock is saturated with gas (as is usually the case) at the critical instant when the pressure is released, the gases explode and the lava is blown into fragments. The largest blocks fall near the volcano and are known as "agglomerate." Fragments from the size of a cocoanut to that of a peanut are known as "scoria" or "ash." The finer pieces—which may be held in suspension in the air for years—are known as volcanic "dust." The gorgeous sunsets of 1883, 1884, and 1885 were due to volcanic dust ejected by the great eruption of Krakatoa in 1883. The moisture discharged in an eruption may be carried several miles into the air. It is there condensed as rain and is precipitated through the dust-filled atmosphere, causing torrents of mud. Thus Pompeii was buried under volcanic scoria, and Herculaneum was choked and filled over by volcanic mud.

It is generally believed by geologists that volcanic activity is decreasing, but slowly. It is certain that it is periodic, but the length and character of the periods cannot be determined until a number of related problems, such as sunspots, the shifting of the earth on its axis, the extent and character of radio-activity, etc., have been determined.

CHAPTER IX

EROSIONS AND LANDSLIDES

ALL superficial agents are manifestations of solar energy, as indeed is circulating water which penetrates a certain distance below the surface. These are usually termed destructive and reconstructive processes, words which describe the work rather than define them. It can scarcely be said that the matter of the earth is destroyed or that it is reconstructed, but it may perhaps be said that it is destroyed as one form of rock and built up again as another. Thus, for example, a granite cliff, against which the sea dashes, will little by little be worn away. The particles thus worn away are sand, and this sand, under suitable pressure and heat, will become sandstone, a very different material from granite. Thus it is possible to say that the granite has been destroyed and the sandstone constructed, but it must not be forgotten that the particles of matter themselves have simply changed their order of arrangement. These two processes are complementary; for, since matter is indestructible, and can have only its position and physical and chemical relations changed, it is obvious that what is removed in one place must be laid down in another. In studying the work of the surface agents, the logical order of treatment requires that the destructive operations be considered first. The agencies to be examined are: (1) The atmosphere, (2) running water, (3) ice, (4) lakes, (5) the sea, (6) animals and plants. Of these various agents the work is principally mechanical,

but water, in its various forms, is a slow but extremely efficient agent of chemical changes.

The atmospheric agencies are by far the most important of the destructive or denuding agents, because no part of the land surface is altogether exempt from their activity. Their work is described by the general term weathering and is shown at once by the different appearance of freshly quarried stone from that which has been long exposed in the face of a cliff, or even in ancient buildings. While such agents as rivers and the sea do work that is much more apparent and striking than that of the atmosphere, yet they are more locally confined, and even in their operations the atmosphere renders important aid.

There are, in the first place, the great differences of climate to be considered, differences in the amount and distribution of the rainfall, of temperature and of the winds, and, in the second place, the resistance offered by the various kinds of rocks to the disintegrating processes. The outcome of all these varying factors is to produce very irregular land surfaces. While the tendency of the atmospheric agencies is gradually to wear down the land to the level of the sea, yet in that process some parts are cut away much more rapidly than others, and hence the first effect of denudation is an increasingly irregular surface.

The atmospheric agents may be conveniently divided into (1) rain, (2) frost, (3) changes of temperature, (4) wind.

The work of the rain, which is both chemical and mechanical, varies greatly in accordance with climatic factors. Amount, frequency and violence of the precipitation, together with its temperature and regularity, all modify the effect. Perfectly pure water would act upon rocks with extreme slowness, but such water is not known to occur in nature. The raindrops, formed by the condensation of the watery vapor of the atmosphere, absorb certain gases, chiefly oxygen and carbon dioxide, which very materially increase the solvent power of the water.

One of the first and simplest effects of atmospheric moisture consists in the hydration of the minerals exposed to it. Hydration, the taking up of water into chemical union, is an important agency of decay, since it causes an increase of volume and thus greatly increases the pressure in the lower parts of rock masses, causing them to keep breaking into smaller and smaller blocks. Oxidation affects especially the iron minerals and thus brings about conspicuous color changes, for iron compounds form the principal coloring matter of the rocks and soils. An especially important and widespread change is carbonation, due to the carbon dioxide which all natural waters contain in greater or less quantity.

Finally, solution plays a highly important rôle in the destructive work of the rain. All rocks contain some soluble material, and when this soluble material is removed, the rock crumbles into a friable mass, which, on complete disintegration, forms soil. This may be illustrated by a block of frozen earth, which is as hard as many rocks, being cemented by the ice crystals, which bind the particles of soil together. When the ice is melted, the mass immediately becomes incoherent. So, in the rocks, the removal of even a small quantity of soluble material often causes the whole to crumble.

Most igneous rocks are made up of crystals of some kind of felspar, associated with such minerals as augite, hornblende and quartz. In granite, for example, rain-water slowly attacks the orthoclase by dissolving out the potash, probably as a carbonate, and also a considerable proportion of the combined silica, and the decomposition finally results in the formation of clay, through which are scattered flakes of mica (if mica were originally present) and the unaltered grains of quartz.

Rocks which are themselves composed of substances derived from the decay of older rocks are attacked in their turn and yield material for new formations. These derivative rocks, such as sandstones, slates and limestones, are

affected in characteristic ways by the rain. In a sandstone with siliceous cement the action is excessively slow, atmospheric waters having very little effect upon silica, but underground it is slowly attacked. The uppermost layers of red sandstone are completely disintegrated into loose sand, bleached by the removal of the iron which gave it its color. In sandstones and slates it is the cementing substance which is removed, leaving the grains of sand or particles of clay unchanged, and with calcareous cement disintegration is rapid. Slates and shales, by removal of their soluble constituents, crumble down into clay.

Limestones, chiefly or entirely carbonate of lime, are attacked by rain-water, dissolved and carried away in solution, while the insoluble impurities contained in the rock remain to form soil. The gradual formation of soil by the disintegration of rock may be easily observed in excavations, even shallow ones, such as cellars, wells, railroad cuttings, and the like. At the surface is the true soil, which is usually dark-colored; next follows the subsoil, which, owing to the absence of vegetable matter and the less complete oxidation and hydration, is of a lighter color. By imperceptible gradations the subsoil shades into what looks like unaltered rock, but is friable and crumbles in the fingers; this is 'rotten rock.' From this to the firm, unchanged rock the passage is equally gradual.

The mechanical effect of rain is less extensive perhaps than its chemical work of disintegration, but is very important, nevertheless. Under ordinary conditions this mechanical work consists in the washing of soil from higher to lower levels. How considerable is the movement of soil that has thus been brought about may be imagined when one sees, after a heavy rain, the rills which run over the slopes, muddy and charged with sediments, and how turbid the streams become with the soil which the rain washes into them. The mechanical action of rain is greatly increased by extreme violence and volume of precipitation; a

single "cloud-burst" will do far more damage than the same quantity of rain falling in gentle showers.

One of the most remarkable monuments of rain erosion is exhibited by the curious districts in the far Western States known as the Bad Lands, which cover many thousands of square miles in the Dakotas, Nebraska, Wyoming, Utah, etc. The bad-land rocks are mostly rather soft sandstones and clays, with prevailingly calcareous cements, and formed in nearly horizontal beds or layers. The rainfall is light, tho torrential showers sometimes occur, but

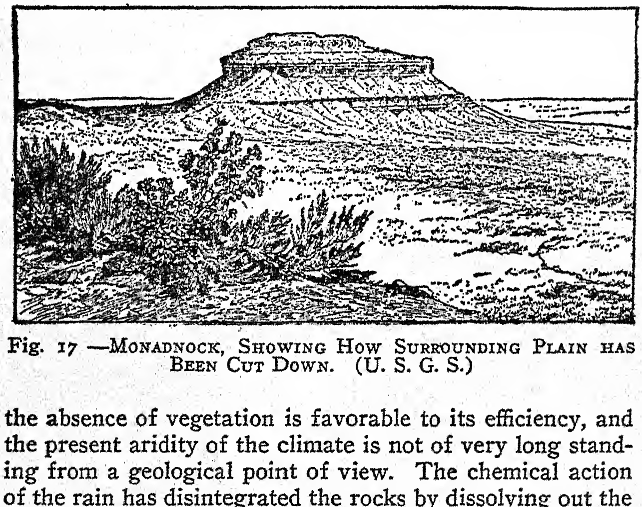


Fig. 17 —Monadnock, Showing How Surrounding Plain has Been Cut Down. (U. S. G. S.)

the absence of vegetation is favorable to its efficiency, and the present aridity of the climate is not of very long standing from a geological point of view. The chemical action of the rain has disintegrated the rocks by dissolving out the calcareous cement, and then the débris so formed has been mechanically washed away.

Differential weathering, or irregular disintegration, has resulted in that remarkable variety and grotesqueness of form resembling the ruins of gigantic towers and castles, for which the bad-land scenery is famous. The removal of the protecting vegetation is often speedily followed by dis-

astrous results, and especially the reckless and wanton destruction of the forests, which has gone on in this country ever since its settlement by Europeans, has been followed by the loss of valuable soil on a vast scale.

The term frost, as a surface agent in dynamical geology, is restricted to the freezing of water. Water is one of the comparatively few substances which expand considerably on solidifying. This expansion amounts to about one-eleventh of the original bulk of the water, and, exerting a pressure of somewhat more than 2,000 pounds per square inch, takes place with irresistible power, bursting thick iron vessels like egg-shells. All rocks are divided into blocks by joints and are traversed by minute crevices, rifts and pores, all of which openings take up and retain quantities of water, as may readily be seen by examining freshly quarried stone.

The water freezes and forces out the large blocks and shatters them into pieces of smaller and smaller size. The fragments thus formed are called talus, and great accumulations of such blocks are formed at the foot of cliffs in all regions where the winters are at all severe. Alternate freezings and thawings not only break up rocks, but cause the broken fragments and soil to work their way down slopes. Each freezing causes the fragments to rise slightly at right angles to the inclined surface, and each thawing produces a reverse movement; hence the slow creep down the slope.

Immense accumulations of frost-made talus are to be found in such places as the foot of the Palisades of the Hudson and at Sherman, where the Union Pacific Railroad crosses the "continental divide," the ground is covered for miles with small, angular fragments of granite broken uo by the frost.

Sudden changes of temperature form another of the processes by which rocks are broken. Their influence is greatest where the changes are most extreme, as in arid regions, especially high mountains and plateaus. The ex-

posure of a naked rock to the burning rays of the sun, followed by the rapid radiation in thin air, causes extreme expansion and contraction. As, however, the heat has penetrated some distance into the interior of the rock and the surface cools first the cause is that of a cooling exterior trying to contract upon a heated, expanded interior. The rock not being susceptible of sudden elasticity, the interior refuses to contract in obedience to the demands of the exterior, and when the latter endeavors to contract the passive resistance of the expanded interior causes the surface to crack and break.

Certain rocks, notably granites, exfoliate under extreme temperature changes; that is, the surface portions split off in large sheets, which may be of almost any thickness, and are either flat or, more commonly, are curved. The effect is frequently the disintegration of rocks into minute fragments. This is especially noteworthy in those igneous rocks which are coarsely crystalline.

The force of the wind bearing particles of sand acts like emery and becomes a disintegrating agent of importance. This agency is of small efficiency in regions of ordinary rainfall, because in these the soil is protected and held together by its covering of vegetation, but on sandy coasts the force is intense. In a Cape Cod lighthouse a single heavy gale so ground a plate-glass window as to render it opaque and useless. Glass is far harder than many rocks so that the latter are quite rapidly abraded and cut down by the drifting sand. The softer parts are cut away first, leaving the harder layers, streaks or patches standing in relief. In this way very fantastic forms of rocks are frequently shaped out; pot-holes and caverns are excavated by the eddying drift, and archways cut through projecting masses. Isolated blocks are sometimes so symmetrically cut away on the under side that they come to rest upon a very small area and form rocking stones, which, in spite of their size and weight, may be swung by the hand. Slowly as they work, the wind and temperature changes prevent

any complete stagnation in the circulation of material, and thanks to them, the processes of disintegration of rock and transportation of soil are kept up even in the dryest deserts.

"The source of all running water," says Scott, "whether surface or underground, is atmospheric precipitation. The rain-water which falls upon the land is disposed of in three ways: One part is returned to the atmosphere by evaporation, another part flows over the surface to the nearest watercourse, the remainder sinks into the soil to a greater or less depth, and tho some of it is returned to the surface in springs, yet a great part must reach the sea by subterranean channels."

The relative proportions of these three parts of the total precipitation vary much in accordance with the climate and with the topography of the land surface. At a depth below the surface, which varies greatly at different times and places, the soil and rocks are saturated with water, which is called the ground water. Near bodies of surface water it may be very little below the surface of the ground, while in arid regions, with irregular topography, it may sink to great depths. In the eastern United States the ground water is encountered at depths of 1-100 feet, as is shown by the countless wells which are supplied by it. In the plateau of the Colorado River, which is dissected by profoundly deep cañons, the ground water is, in places, nearly 3,500 feet from the surface. The level fluctuates with the rainfall, rising in wet seasons and sinking in dry.

It is usual to regard the ground water as everywhere penetrating to great depths, but as Spurr briefly says: "It is probable that the universal presence of ground water is characteristic of a comparatively shallow surface belt, below which the water which has not been again drawn off at the surface, at a lower level, or has not been used up in hydration processes, is concentrated into the larger fissures."

The factors which determine flow are the inclination of the stratified rocks, the alternation of porous and impervi-

ous beds, and the character of the joints and fissures and not surface topography. The water, seeping downward through the joints and bedding planes, exerts its solvent and decomposing action upon the walls of these crevices, in the manner already described in connection with the work of rain. Down to the level of the ground water, or in the shell of weathering, percolating waters are the great

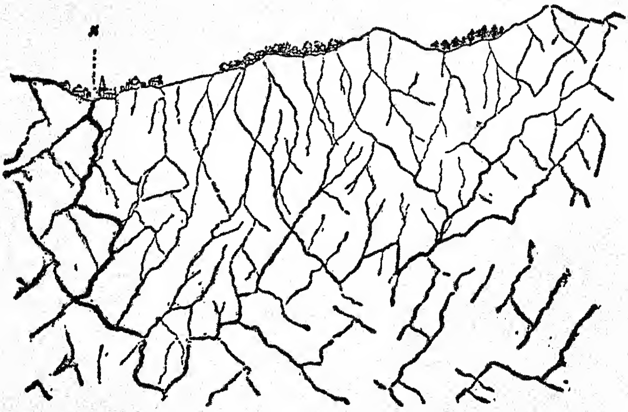


Fig. 18 —PERCOLATION OF GROUND WATER.

agent of decomposition and therefore always contain more or less mineral matter in solution, the nature and quantity of which depend upon the character of the rocks traversed. Below the ground water level in the shell of cementation the effects are more reconstructive than destructive, tho solution and alteration of minerals continue at these lower levels.

In passing through limestone, percolating waters dissolve channels which sometimes enlarge into caverns. The Mammoth Cave, in Kentucky, covers several square miles, and Professor Shaler estimated the length of the passages

at 100,000 miles. When underground waters become highly heated through contact with hot volcanic masses their solvent efficiency is greatly increased. Rocks penetrated by such thermal waters are profoundly altered in character and composition.

Except in caverns, underground waters flow too slowly to accomplish direct mechanical erosion, but indirectly they may bring about important mechanical changes. Masses of soil or talus, lying on steep slopes, saturated by long-continued, heavy rains, may have their weight so increased

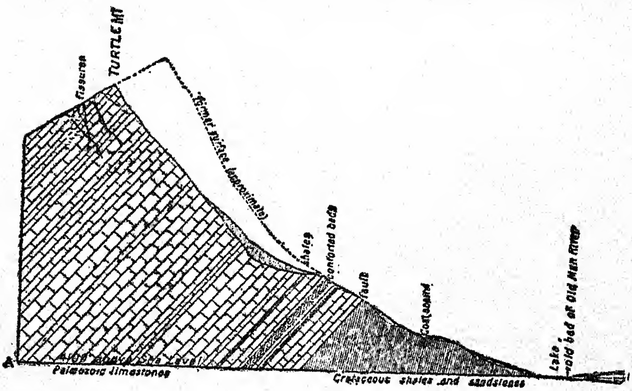


Fig. 19 —LANDSLIDE SHOWING PLACE WHEREFROM FORTY MILLION CUBIC YARDS OF ROCK FELL.

and their friction so reduced as to cause landslides. Rock slides occur in a similar manner. In 1903 at Frank, Alberta, in Canada, the entire face of Turtle Mountain fell and rushed across the valley in a huge avalanche of broken rock, estimated at 40,000,000 cubic yards.

The effect of this seepage appears wonderfully in springs, which are merely the openings of the ground water upon the surface, due to the force of gravity, in that the source of a spring is always higher than its mouth. A

spring usually is formed when a relatively impervious bed of rock (usually clay in some form) overlaid by porous rocks crops out on a hillside. The ground water saturates the lower layers of the porous beds until its descent is arrested by the impervious bed, and then the water follows the upper surface of the latter. When, by some irregularity of the ground, the impervious bed comes to the surface, the water will issue as a spring or a line of springs.

Other springs rise through a crack or fissure in the rocks. Inclined porous beds, enclosed between more impervious ones, allow the water to follow them downward. On reaching a fissure opening upward, the water will rise

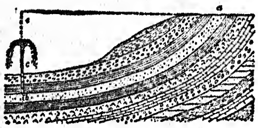


Fig. 20 —GUSHING SPRING.

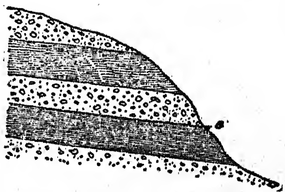


Fig. 21 —FLOWING SPRING.

through it and, if it is under sufficient pressure, will reach the surface.

An artesian well is an artificial fissure spring. It is a boring which taps a sheet or stream of the ground water, when the water is under sufficient pressure to rise to the surface or even spout high above it.

The underground streams, of which springs are the outlets, often have effected much in the way of dissolving rock material, and hence spring-water always contains dissolved minerals, principally the carbonates and sulphates of lime and magnesia and the chlorides of magnesium and sodium. In 'mineral springs' the quantity of dissolved materials is larger and perceptible to the taste.

The narrow bed of a river has the effect of making its destructiveness more apparent, but as a whole rivers are

less potent than the atmospheric agencies. A certain amount of solution and decomposition is performed by rivers upon the rocks of the bed, and in limestones this may be considerable, especially if the water be charged with organic acids from a swamp or peat-bog.

As in the case of the wind, the stream merely supplies the power; the implement with which the cutting is performed is the sand, pebbles and other hard particles which the water sets in motion. These abrade the rocks against which they are cast, just as the wind-driven sand does, but more effectively, because of the ceaseless activity of the stream, and because many rocks are rendered softer and more yielding by being wet. The mechanical work is dependent upon the velocity of the current varying directly as the square of that velocity. Angular blocks are speedily worn into cobblestones and these into pebbles of spheroidal or flat, discoidal form. A process of selection goes on, by which the softer materials are ground into mud, the harder remaining as pebbles and sand.

Sudden fluctuations of volume in a river, so that it is now a rushing torrent and again almost dry, is a much more efficient agent, both of erosion and of transportation, than is one which carries nearly the same quantity of water at all times or which fluctuates only slowly. In eddies and at the foot of cascades the water acquires a rotary motion, which is transmitted to stones lying on the bottom. In a rocky bed these revolving stones excavate cylindrical holes, often of remarkable regularity, called pot-holes, or giant kettles. Unassisted by other agencies, a river cuts a narrow, steep-sided trench or gorge.

As soon as the gorge begins to form, its sides are attacked by the atmospheric destructive forces and a process of widening is begun; but this is very slow and to widen out the gorge or cañon into a broad valley, with gentle slopes, requires a very long period of time, determined by the activity of the climate and the resistant power of the rocks. Rarely is a river valley straight for any consider-

able distance, but takes a sinuous course, with rocky spurs projecting alternately from opposite sides of the stream. This is true even of swift streams flowing through hard rocks, and the tendency is much exaggerated when the velocity of the current is diminished and the river-bed is in soft materials, as in the lower Mississippi.

Having learned the general character of river erosion, a few concrete examples will be interesting. A particularly valuable case is that of the little river Simeto in Sicily, since the history of its gorge is so well known. In 1603 a great lava flood from Ætna was poured out across the course of the stream, and, when cold, solidified into a barrier of the hardest rock. When Sir Charles Lyell visited the spot in 1828 he found that in a little more than two centuries the stream had cut a gorge through this barrier of 40 to 50 feet deep and varying in width from 50 to several hundred feet. The lava which had thus been trenched is not porous or slaggy, but homogeneous, dense and very hard. In the northern parts of the United States the great ice sheet brought down with it vast quantities of drift that filled up the channels of many streams and quite revolutionized the drainage of certain districts. Since that time the displaced streams have cut out new channels for themselves. Au Sable Chasm, New York, is an example of these geologically modern river gorges, the atmosphere not having had time to widen it.

The Niagara is an exceptional case, the gorge being cut, not only by the direct abrasion of the running water, but also by the action of the spray and frost at the falls. In the ravine the upper rock is a hard, massive limestone, which is underlaid by a soft clay shale. The latter is continually disintegrated by the spray of the cataract and by the severe winter frosts undermining the limestone, which, when no longer able to bear its own weight, breaks off in tabular masses. Thus the falls are steadily receding, leaving behind them a gorge, which is deepened by the river and

especially by the plunging masses of water at the foot of the cataract.

One of the most remarkable known examples of river erosion is seen in the cañons of the Colorado. The Grand Cañon is over 200 miles long and from 4,000 to 6,500 feet deep, with precipitous walls. It is extremely probable that the river has been rendered able to cut to such profound

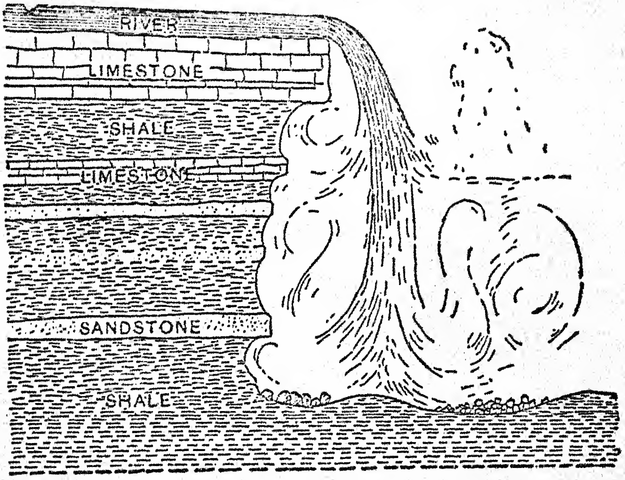


Fig. 22 —Strata at Niagara Falls.

depths by the gradual uplifting of the whole region, which is now a lofty plateau, in places more than 8,000 feet above the sea.

The scope of the transporting power of running water is dependent upon the velocity of the current. If the rapidity of a stream be doubled, it can carry 64 times as much as before, being as the sixth power. The destructiveness of sudden and violent floods is thus explained. In the terrible flood which overwhelmed Johnstown, Pennsylvania,

in 1889, great locomotives and massive iron bridges were swept off, it is hardly an exaggeration to say, like straws, and huge boulders carried along like pebbles.

The quantity of material which rivers are continually sweeping into the sea is enormously great. Every year the Mississippi carries into the Gulf of Mexico nearly 7,500,-000,000 cubic feet of solid sediment, either in suspension or pushed along the bottom, an amount sufficient to cover one square mile to a depth of 268 feet. In addition to this is the quantity brought down in solution, which is estimated at 2,850,000,000 cubic feet annually. And yet this astounding volume only represents a lowering of the surface of the entire drainage area at the rate of one foot in 4,920 years, for it must be remembered that North America's great river drains 1,325,000 square miles.

In addition to the destructive agencies of the atmosphere and of running water, the sea plays a large part. Upon the coast line, whether it be rock or beach, the waves dash interminably, not only possessing the force which has been imparted to them by the wind but also from the tension of oceanic current and the tides. According to observations made for the Scotch Lighthouse Board, the average wave pressure on the coast of Scotland is for the five summer months 611 pounds per square foot and for six winter months 2,086 pounds. These are average figures and are greatly exceeded in storms, when the force of the breakers often rises to many tons per square foot.

The gentlest movements have some grinding action among the sands, while the heaviest may dislodge and move along, up the shores, rocks many tons in weight. Niagara wastes its power by falling into an abyss of waters, but in the case of the waves the rocks are bared anew for each successive plunge. The waters are often loaded with gravel and sand when they strike, and thus carry on abrasion. Cliffs are undermined, rocks are worn to pebbles and sand, and, through mutual friction, sand is ground to the finest powder. Rocky headlands on wind-

ward coasts are especially exposed to wear, since they are open to the battering force from different directions.

The coast of Yorkshire in England is washed away at an average rate of nearly seven feet per annum. The island of Heligoland, near the German coast, has suffered great loss from the attacks of the sea within historic times; the small eastern island was cut off from the larger island, Heligoland proper, by a great storm in 1720. At Long Branch, New Jersey, the sandy bluffs must be artificially protected against the attacks of the sea; yet in spite of such protection almost every severe gale does considerable damage. Sandy coasts which are low-lying and flat often suffer less from the inroads of the sea than rocky and precipitous ones, but even such coasts may, however, be rapidly cut back. Limestone coasts suffer from solution by sea-water and are characterized by long caverns and tunnels, tho sea caves are worn by the surf in all classes of rocks.

Of far less influence are the lakes, which indeed are to be regarded as merely temporary bodies of water and which either by being filled up or by the gradual wearing away of a barrier which obstructs them will disappear. In the Great Lakes there are small tides and small breakers, which in all details follow the nature of marine destruction, but on a far smaller scale.

It is otherwise, however, with snow and ice; snow in the form of avalanches, which frequently bring down with them masses of earth, and ice in the form of glaciers. "A glacier," says Scott, "is a stream of ice which flows as if it were a very tough and viscous fluid, and does not merely glide down a slope, as snow glides from the roof of a house. Their contribution to the sum total of rock destruction and reconstruction is relatively small, but their former extension has a wide bearing upon some of the most far-reaching of cosmical problems.

"The height, in the Alps, of the snow-line, or that below which the snow annually precipitated melts during the year,

is about 8,400 feet on the north side of the Alps and about 8,800 feet on south side, and the glacier may descend below this line 5,000 feet or more. Tho starting where all is white and barren, it passes by regions of Alpine flowers and often continues down to a country of gardens and human dwellings before its course is ended. Thus the Glacier des Bois, an upper portion of which is called the Mer de Glace, rises in Mont Blance and other neighboring peaks and terminates like several other glaciers, in the vale of Chamouni. In a similar manner two great glaciers descend from the heights of the Bernese Alps to the Grindelwald valley just south of Interlaken."

Snow is made up of minute, hexagonal crystals of ice, which are intimately mixed with air and thus separated from one another. Ice is composed of the same kind of crystals as is snow, but they are in contact with one another, not separated by air. To convert snow into ice it is only necessary to expel the air and bring the crystals into contact, for which pressure alone is not ordinarily sufficient.

The first step in the transformation is the partial melting of the upper layers of snow. The water thus formed trickles down into the snow beneath, expelling much of the air. This underlying snow has still a temperature much below the freezing point, and the percolating water is soon refrozen into little spherules of ice. This substance, midway between snow and ice, is called névé. The air, which is now in the form of discrete bubbles, is largely expelled by the increasing pressure of the overlying snow masses, which are continually added to by renewed falls, and the névé is thus converted into ice.

A glacier moves in much the same way as a river, but at a very much slower rate. The middle portion moves faster than the sides, because the latter are retarded by the friction of the banks, and, for the same reason, the top moves faster than the bottom. While behaving like a plastic substance under pressure, ice yields readily to tension, and

even a slight change in the slope of the bed will cause a great transverse crack, or crevasse, to form. Marginal crevasses are formed along the sides of the glacier and are due to the more swiftly moving middle pulling away from the retarded sides.

The rate of glacier movement depends upon the snow supply, upon the slope of the ground and the temperature of the season. The great stream of ice which enters Glacier Bay in Alaska has a summer velocity of seventy feet per day in the middle.

Newly formed glaciers remove the soil, talus and other loose material from the surface and then the bare rocks are eroded by a double process: The joint-blocks are torn away by the advancing ice, an operation which is much facilitated by the continual liquefaction and relegation of the ice at the bottom of the glacier, owing to changes of pressure, for it must be remembered that the melting point of ice varies with the pressure and this is continually changing, due to the motion of the glacier and inequalities of the bed, and in this manner the joint-blocks of the bed-rock are loosened. The bottom of the glacier is a mass of ice mingled with rocks, pebbles, boulders, sand and débris of all sizes, and by their means the bed-rock is worn down, smoothed, polished and scored with parallel marks in a fashion which forms the unmistakable autograph of the glacier.

"In the lower part of a glacier," says Dana, "the several moraines generally lose their distinctness, through the melting of the ice and also by reason of the fact that the glacier is generally compressed in its lower part to a width very much less than the aggregate width of its tributaries. The surface of the glacier, accordingly, often becomes covered with earth and stones for the greater part of its breadth. The bluff of ice which forms the foot of a glacier is often a dirty mass, scarcely revealing superficially its real nature.

Besides the superficial moraines, a glacier also gathers rock material from the bottom over which it moves. The disintegrated and decomposed rock is mostly scraped from the surface, masses of rock are torn off from jointed ledges, and soft rocks in the path of the glacier are deeply abraded.

The final melting leaves all the earth and stones in unstratified heaps or deposits, which may be further transported, abraded and deposited by the stream that flows from the glacier. The mass of such deposits dropped at the foot of a glacier is called the terminal moraine.

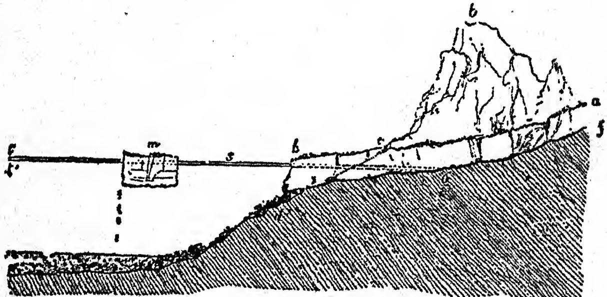


Fig. 23 —DÉBRIS CARRIED BY GLACIER AND DROPPED ON THE SEA BED.

River, lake and coast ice also transport material. When a glacier enters the sea it plows along the bottom until the buoyant power of the water breaks off great fragments of it, which float away as icebergs. These are often of gigantic size, veritable islands of ice, and huge as they appear, only about one-ninth of their bulk is above water. As icebergs are derived from glaciers, they carry away whatever débris the parent glacier had upon or within it, and, wherever they melt, they drop all to the ocean's bottom. The sea about the Newfoundland banks is one of the regions of melting icebergs; and there is no

doubt that vast submarine accumulations of such material have been made there by this means.

Organic forces also play a part. Seeds germinating in the crevices of rocks, or the roots of trees which invade such crevices from above, wedge the rocks apart with the same irresistible power as is displayed by frost, and often large areas of rock are thus most effectively broken up. Many marine animals bore into rocks, even the hardest, and cause them to crumble, and on the land great numbers of animals continually bore and tunnel through the soil, allowing a freer access of air and water. In the tropics the soil is fairly alive with the multitude of burrowers.

Earthworms are among the most important agents in work of this kind. The worms swallow quantities of earth for the sake of the organic matter which it contains and grind it exceedingly fine in their muscular gizzards. This ground-up soil is always deposited on the surface, in the form of the coiled "worm-castings" so abundant in grassy places. In England the material thus yearly brought to the surface varies from seven to eighteen tons per acre, which means an average annual addition of one-tenth to one-sixth of an inch. In the tropics ants and termites (so-called white ants) are even more active than worms in tunnelling the soil, and in many semi-arid plains burrowing mammals in incredible multitudes are continually working over the soil to great depths, as in the prairie-dog villages of our Western plains. The occasional heavy rains thus penetrate to depths which could not otherwise be reached.

The immense influence exerted by man upon the changing condition of Physical Geography has been summarized by Geikie. The great geologist regards him as a factor antagonistic to the methods and designs of Nature. "Not content with gathering the fruits and capturing the animals she has offered for his subsistence," he says, "Man has, with advancing civilization, engaged in a contest to subdue the earth and possess it. His warfare, indeed, has often been a blind one, successful for the moment, but

leading to sure and sad disaster. He has, for instance, stripped off the woodland from many a region of hill and mountain, gaining his immediate object in the possession of their stores of timber, but thereby laying bare the slopes to parching droughts or fierce rains. Countries once rich in beauty and plenteous in all that was needful for his support are now burnt and barren or washed bare of their soil. It is only in comparatively recent years that he has learned the truth of the aphorism, 'Homo Naturæ minister et interpres.'

"Human interference affects meteorological conditions by removing forests and laying bare to the sun and winds areas which were previously kept cool and damp under trees, or which, lying on the lee side, were protected from tempests; by drainage, the effect of this operation being to remove rapidly the discharged rainfall, to raise the temperature of the soil, to lessen the evaporation, and thereby to diminish the rainfall and somewhat increase the general temperature of a country; by the other processes of agriculture, such as the transformation of moor and bog into cultivated land and the clothing of bare hillsides with green crops or plantations of coniferous and hardwood trees.

"By increasing or diminishing the rainfall, man directly affects the circulation of water over the land; by the drainage operations, which cause the rain to run off more rapidly than before, he increases floods in rivers; by wells, bores, mines or other subterranean works, he interferes with underground waters and consequently with the discharge of springs; by embanking rivers, he confines them to narrow channels, enabling them to carry their sediment farther seaward, and in a thousand other ways his influence is felt."

CHAPTER X

RECONSTRUCTIVE PROCESSES

It has been pointed out, in the work of 'destruction,' that in the true sense of the word it is not destruction at all, but rather a preparation for building anew. It is at the same time the closing of one period of existence for a certain group of particles of matter and the beginning of another. But while the active agencies that lead to the breaking down of former masses are numerous, in the strict sense of the word the reconstruction agency is only one—that of sedimentation. The new rock is built out of the old, tho under differing conditions and with different results.

At the present time it is estimated about one-half of the waste of the land is carried directly into the sea, while the remainder is arrested in its journey and deposited upon the land. The accessible rocks of the earth's crust are more largely composed of marine deposits than those laid down in other ways, yet the non-marine sedimentary rocks are also extensively represented. A natural division of the sedimentary accumulations is into the marine and the continental, including in the latter the deposits which are made upon the land, or in such bodies of water as are not parts of the sea.

"It is an almost universal characteristic of sedimentary accumulations," says Scott, "whether modern deposits or ancient rocks, that they are stratified; that is, divided into more or less parallel layers or beds. Strati-

fication is due to the sorting power of water, or of the wind, by which, so long as conditions remain the same, particles or fragments of similar size and weight are thrown down at the same spot. Layers clearly demarcated from one another may be produced in either one of two ways: (1) By such a change of conditions that the material deposited changes abruptly, tho perhaps only as a mere film of a different substance; or (2) by a pause, however brief, in the process of deposition. The planes of contact between the successive layers, which may be indistinct or very sharply defined, are called the bedding or stratification planes." Each bed is made up of some predominant substance in a state of greater or less purity, such as gravel, sand or clay, due to the sorting powers of the water, and thus heterogeneous material is separated into its constituent parts, tho the separation is rarely quite complete, and sometimes there is hardly any separation at all. In the sea, or a large lake, the material on the bottom grows finer outward from the shore, while a river, whose velocity diminishes from headwaters to mouth, lays down material of decreasing coarseness, from the boulders and cobbles of the headwaters to the fine silt of the lower course.

Wherever a sandy soil occurs, unprotected by vegetation, as in deserts or along the seacoast, the wind drifts the sand and piles it up into hills or sand dunes. When the sands are mixed with pieces of shells and other calcareous material, percolating waters, by dissolving and redepositing the carbonate of lime, may cement the sands into firm rock. This is the more conspicuous when the whole material is calcareous, as in the shell sands of Bermuda.

Springs also form siliceous deposits, but they are rare, and the carbonate of iron is deposited as chalybeate. Phosphate deposits are also made in rainless regions, where guano, the accumulated excrement of birds, piles up to great thicknesses without the loss of its soluble matter.

Cave deposits are usually chemically formed, and are due to the solution and redeposition of carbonate of lime. At first, the deposit is white, opaque, and very friable, crumbling at a touch, but repeated depositions fill up the interstices of the porous mass and convert it into a hard, translucent stone, which assumes a crystalline structure through the development of calcite or aragonite crystals.

The masses thus formed that depend from the roof of the cavern are called stalactites. After hanging for a time from the roof the drop of water falls to the floor of the cave, and there, in similar fashion, deposits a little layer of carbonate of lime, which gradually grows into a cone. This is a stalagmite, and differs from the stalactite only in the fact that it grows upward from the floor instead of downward from the roof. The stalagmite is, of course, exactly beneath the stalactite, and as long as the water continues to follow the same path the two cones are steadily, tho very slowly, increased both in height and thickness, until they meet, unite, and form a pillar extending from floor to roof of the cavern. These deposits form the curious and beautiful features of limestone caverns.

The vegetable accumulations are the most important of the swamp and bog deposits, for the preservation of which a certain amount of water is necessary. The vast quantities of coal which occur in so many parts of the world testify to the significance of the part which bog and swamp accumulations of vegetable matter have played in the earth's history. The nearest approach to coal in process of formation at the present day is in the peat bogs, which are especially abundant and extensive in cool, damp climates, as in Ireland, Scandinavia, and the northern parts of South America.

The Great Dismal Swamp of Virginia and North Carolina probably more nearly reproduces than do most existing peat bogs the conditions of the ancient coal swamps. The swamp, which measures thirty miles by ten, is a

dense growth of vegetation upon a water-covered soil of pure peat about fifteen feet deep, and with no admixture of sediment. The swamp cypress grows abundantly in the bog, and prevents, by its dense shade, the evaporation which would take place in summer could the sun's rays penetrate to the wet soil. The shallow layer of water which covers the ground receives the fallen leaves, twigs and branches, and sometimes even the trunks of fallen trees, preventing their complete decomposition, while the dense covering of mosses, reeds and ferns which carpet the ground add their quota to the mass of decaying vegetable matter.

The accumulations at the mouths of rivers, generally known as deltas, have, from ancient times, been the means of showing Man in what manner the configuration of the surface of the earth was changing. The delta at the mouth of the Nile is a typical case in many ways, and its working was observed by the older nations that bordered the Mediterranean. This is more especially noticeable in the Nile, for there was added to the problem the question of why the delta did not advance further into the sea (due to a swift current along the sea front), and this led to an investigation of the Mediterranean currents.

But the delta of the Mississippi, on the other hand, is advancing rapidly, about 110 yards a year, or 27 feet a month, a speed which, if it be extended to long geological ages, is amazing. Extraordinary tho it may seem, a week's stay at the mouth of the Mississippi is enough to see perceptibly the surface of the Earth changing shape. Débris brought down by the Indus, a swifter stream, instead of forming a delta with a sluggish current, has been carried to the ocean, where it has made a shoal covering an area of 700,000 square miles, a little larger in size than all the States north of Mason and Dixon's line and west of the Mississippi, or five times as large as the British Isles. In the course of time this shoal will rise to the surface, and a new country will have been formed.

The delta formation is seen in small streams entering lakes, and accumulations in the same manner as are made in the ocean beds are to be found in the lake basins. In small lakes the coalescence of deltas, or the advance of a single one, will eventually fill up the basin, forming first swamps and then smooth, grassy meadows, through which flow the streams, keeping their own channels clear. Such filled-up lakes are common in many mountain valleys.

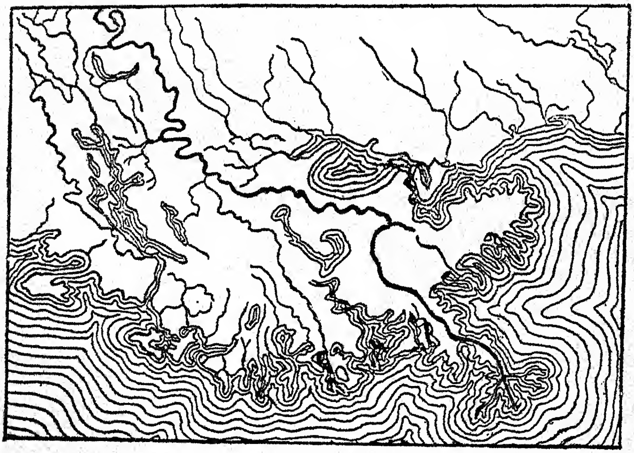


Fig. 24 —Delta of the Mississippi.

Lake deposits betray the form of the basin in which they are laid down. Around the old shore line are masses of coarse materials, with deltas interspersed, to mark the mouths of streams, while toward the middle of the basin quantities of fine mud and clay have accumulated. An excellent example of such a deserted lake basin is that known as Lake Bonneville, in Utah, of which Salt Lake is the shrunken remnant. The drying up of this lake, which was once fresh, and had an outlet northward to

the Snake River, is an event geologically so recent that its form and size, its shores and islands, its high and low stages—in short, its history—can be made out with great clearness, as has been admirably done by Mr. Gilbert of the United States Geological Survey. At its time of greatest extension Lake Bonneville had an area of 19,750 square miles and a maximum depth of 1,050 feet, while Salt Lake (which is variable) had in 1869 an area of

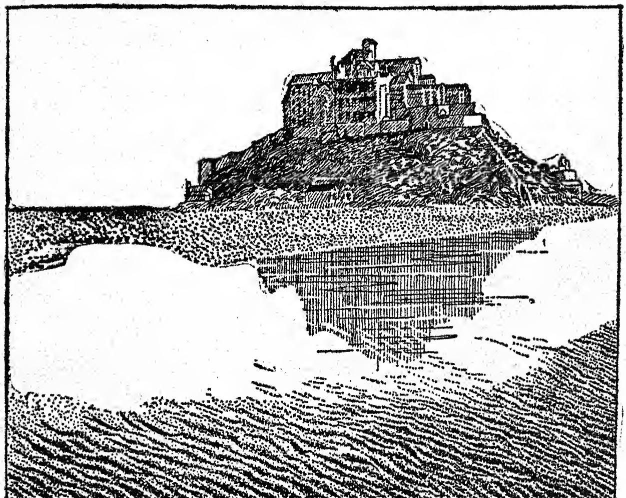


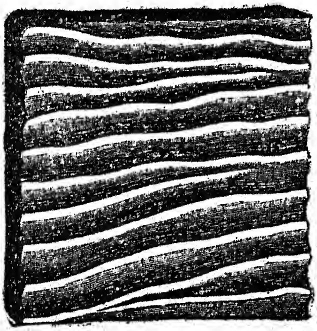
Fig. 25 —Ripple-marks on Sand.

2,170 miles and an extreme depth of 46 feet. Around the ancient shores are preserved the terraces, embankments and deltas of the various stages of water, with the gravels and sands appropriate to the shallow water.

"The sea is the great theater of sedimentary accumulation," says W. B. Scott in his 'Introduction to Geology,' "and rocks of marine origin form the larger part of the

present land surfaces. Important as other classes of deposits may be, they are less so than those laid down in the ocean and the waters immediately connected with it. Marine deposits may be classified primarily in accordance with the depth of water in which they were laid down, one of the most valuable guides to the history of ancient rocks, and secondarily in accordance with the nature of the material of which they are composed and the processes by which they were accumulated.

Ripple marks are formed by the wind or by the rippling movement of water, and may be seen on any sandy



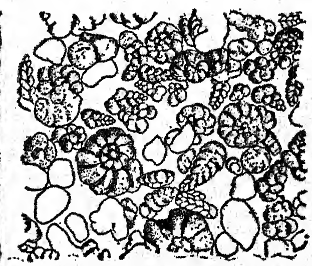


Fig. 26 —Rippled Sandstone. Shells in Chalk.

beach. They occur especially in sands, in shoal-water deposits, as well as in those made on flood plains and in lakes and on sand dunes. They are found in rocks of all geological periods, and tho most frequent in sandstones, occur in other kinds of rocks. Wave marks and rill marks, sun cracks, rain prints, and the tracks of land animals, are preserved in a similar way. It might seem incredible that such slight marks could be preserved for ages in the solid rocks, were it not for the fact that their occurrence is so common.

Where for long distances no large rivers enter the sea,

and the material is all derived from the wear of the coast, the arrangement of coarse and fine deposits is quite regular, and gravel beds may extend as far as ten miles from land. Waves and currents sweep sediment not only toward the shore, but parallel with it, and tend to simplify the coast line by building barriers and spits across the mouths of bays, which the waves may pile up above high tide, as is seen all along the eastern coast of the United States. Behind these barriers streams bring in sediments, filling up the bays and converting them into salt marshes, and eventually into land.

Very near shore currents produce irregularities of stratification, especially the structure known as cross bedding. Nor are the deposits of lime which go to make limestones deposited at the bottom of the sea by organic forms with calcareous exteriors, such as shellfish, starfish, and the coral polyps, to be forgotten. For example, the chalk 'white cliffs of Dover,' which are so characteristic a feature of the coast of the South of England, are composed mainly of tiny shells, many of them so unbroken that they can be picked out by hand, while the whole structure, under a microscope, is seen to be of this order. The creation of huge groups of islands and the extension of the mainland in tropical and sub-tropical waters by the coral polyp is constant.

The fine material derived from the land is generally termed "mud." The color of the mud is different on different parts of the ocean floor. It is blue, red, and green, according to the prevailing coloring matter.

The Abysmal deposits are those the materials of which are not directly derived from the land, but consist of matters carried to the sea in solution and extracted from the sea-water by the agency of organisms, together with volcanic substances in a more or less advanced stage of decomposition. They are generally termed oozes, the most important of which is Foraminiferal Ooze. The Foraminifera are minute animals, each one a tiny speck

of jelly, most of which, in spite of their extreme simplicity of structure, have the power of secreting very beautiful and complex shells of carbonate of lime. As the animals die the shells settle to the bottom in myriads.

Silica is also dissolved in sea-water, and various organisms construct their tests of that substance. The Radiolaria are, like the Foraminifera, a group of microscopic, unicellular animals, which secrete siliceous tests of the most exquisite delicacy and beauty; they live both at the surface and at the bottom of the sea. Radiolarian tests may be detected in all sorts of marine deposits of both deep and shallow water, but it is only in very profound depths that they occur in quantity sufficient to give character to the deposit. In the Antarctic Ocean there is an extensive belt of Diatom ooze, resembling the freshwater deposit, but may be distinguished by the presence of foraminiferal and radiolarian shells and tests.

The profoundest abysses of the ocean, far from any land, are covered with a deposit of red clay, which, tho varying much in composition and color, is yet of a quite uniform character. The clay is derived from the disintegration and decay of volcanic substances, especially pumice, which floats upon water, often for months, and drifts long distances in the ocean currents. Of all the oceanic deposits the red clay is the most widely extended, covering 51,500,000 square miles of the bottom. The excessive slowness with which this abysmal deposit is formed is shown by the occurrence in recognisable quantities of meteoric iron.

"Comparing the marine deposits now accumulating in the sea with the rocks of evidently marine origin which form most of the land," concludes Scott, "we find that the great bulk of these rocks, the sandstones, slates, and limestones, are such as are formed in water of shallow and moderate depths, while only rarely do we discover a rock that implies really deep water."

CHAPTER XI

THE INTERIOR OF THE GLOBE

STRUCTURAL GEOLOGY in many ways is the most intricate of all the divisions of the science, for the reason that all the various factors come into play. Thus while it deals with the substances of which the earth's crust is composed —it is far from being merely descriptive—it must at the same time present, as far as possible, the causes of their placement and the forces which have gone to make up their structure.

The object of Structural Geology is to learn not only the agencies which have produced the structures and the way in which they operated, but also the successive steps by which the rocks originated, the order in which they occurred, and their geological date. The distinction between a rock and a mineral is not always an easy one to grasp, yet it is essential that it should be so. A rock is any extensive constituent of the earth's crust, which may consist, tho rarely, of a single mineral, but in the great majority of cases is a mechanical mixture of two or more minerals. A rock thus has seldom a definite chemical composition or homogeneous internal structure. An examination with the microscope almost always shows that a rock is an aggregate of distinct mineral particles, which may be all of one kind or of many different kinds, in varying proportions. Geologically, incoherent masses of sand and clay are regarded as being rocks quite as much as the hardest granites.

The Igneous Rocks, wherein heat is the chief factor in their making, as the name shows, are truly primary rocks, in the sense that it seems that all other have been made from them. The particles of matter now composing sedimentary and metamorphic rocks have been changed so often that in many cases the relationship to the igneous rock is not easy to trace, but it is there.

As geology is primarily a historical study, the most logical scheme of classification is obviously one that, so far as possible, is genetic; that is to say, one which expresses in brief the history and mode of formation of the rocks. This genetic principle would suggest the division of all rocks into three primary classes or groups: (a) Igneous Rocks, those which were melted and have solidified by cooling; (b) Sedimentary Rocks, laid down under water by mechanical, chemical and organic processes; and (c) Metamorphic Rocks, which have been profoundly changed from their original sedimentary or igneous character, often with the formation of new mineral compounds in them.

The rocks of earliest times, called igneous, have a deep-seated origin and have either forced their way to the surface or have cooled and solidified at varying depths beneath it. They were the first to be formed, and all the others have been derived, either directly or indirectly, from them. The products of the chemical decomposition or mechanical abrasion of the rocks have furnished the materials out of which the sedimentary rocks were formed, at least in the first instance.

The igneous rocks are massive, as distinguished from stratified, and tho sometimes presenting a deceptive appearance of stratification, may always be distinguished from the truly stratified rocks. Characteristic differences appear between those igneous masses which have solidified deep within the earth, called 'plutonic,' and have been brought to light only by the denudation and removal of

the overlying rock masses, and those which have cooled at or near the surface of the ground, known as volcanic.

In order to determine the circumstances under which the rock was formed, the texture of a rock must be observed, and hence great attention is paid to it; and in the igneous group five principal types of texture will be found: 1. Glassy.—A glass or slag without distinct minerals in it, tho the incipient stages of crystallization, in the form of globules and hairlike rods, are often observable with the microscope. When the glass or slag is made frothy by the bubbles of escaping steam and gas the texture is said to be vesicular, scoriaceous or pumiceous, according to the abundance of the bubbles. 2. Compact (or Felsitic).—Characterized by the formation of exceedingly minute crystals, too small to be seen by the unassisted eye, giving the rock a homogeneous but stony and not glassy appearance. 3. Porphyritic.—In rocks of this texture are large, isolated crystals, called phenocrysts, embedded in a ground mass, which may be glassy or made up of small crystals. They have usually solidified near the surface of the ground. 4. Granitoid.—In this texture the rock is wholly crystalline, without ground mass or interstitial paste. The component grains, which may be fine or very coarse, are of quite uniform size, and as the crystals have interfered with one another in the process of formation they have rarely acquired their proper crystalline shape. They have solidified slowly and at great depths. 5. Fragmental.—This is represented by the accumulations of the fragmental products ejected by volcanoes, agglomerates, bombs, lapilli, ashes, etc.

The texture of an igneous rock is determined by the several factors which affect the molten mass during consolidation. Of such factors may be mentioned the chemical composition, temperature, rate of cooling, degree of pressure, and the quantity present of dissolved vapors and gases, which are called mineralizers. Chemical composition determines the fusibility of a rock at a given tem-

perature. The effect of chemical composition upon texture is seen in the rapidity with which the less fusible rocks chill and stiffen, and therefore the greater frequency with which they form glasses. Hence very rapid cooling results in a glass, but the microscope reveals the incipient stages of crystallization in many of even the glassy rocks. A somewhat slower rate of solidification produces a cryptocrystalline rock, and successively slower rates bring about the porphyritic, microcrystalline and granitoid textures.

Pressure is of importance in preventing the rapid escape of the vapors and gases contained in the molten mass, and hence frothy, scoriaceous and vesicular textures cannot be produced under high pressures. The mineralizers, such as steam, hydrochloric acid, and other vapors, determine the crystallization of many minerals which refuse to crystallize in the absence of such vapors. It must not be supposed that a molten magma consists merely of a number of fused minerals mechanically mixed together and having no effect upon one another. Petrographers believe that a molten magma is a solution of certain compounds in others, and that crystallization occurs in the order of solubility, as the point of saturation for particular compounds is successively reached by the cooling mass.

Prof. Kemp has determined the order of formation of minerals in a solidifying magma. First to form are apatite, the metallic oxides (magnetite, ilmenite), and sulphides (pyrite), zircon and titanite. "Next," he says, "come the ferro-magnesian silicates, olivine, biotite, the pyroxenes and hornblende. Next follow the felspars and felspathoids, nepheline and leucite, but their period often laps well back into that of the ferro-magnesian group. Last of all, if excess of silica remains, it yields quartz. It results from what has been said that the residual magma is increasingly siliceous up to the final consolidation, for the earliest crystallizations are largely pure oxides. It is also a striking fact that the least fusible minerals. the felspars and quartz, are the last to crystallize."

The classification of the igneous rocks now most generally adopted is made upon a threefold method, according to texture and chemical and mineralogical composition. In the following table (modified from Kemp's) the textures are given in vertical order, while transversely the arrangement is mineralogical, chiefly in accordance with the principal felspar.

The division of the igneous rocks into families is made primarily in accordance with the mineralogical composition, with subdivisions according to texture. This method gives us five principal groups: (1) The Granite Family. This family includes the dark volcanic glass, obsidian; pumice, which is generally known; rhyolite, quartz porphyry and granite. (2) The Syenite Family. The chief rocks included are syenite obsidian, trachyte, phonolite, syenite and nepheline syenite. (3) The Diorite Family. There are but three important rocks in this class, andesites, dacites, and the diorites. (4) The Gabbro Family. This includes basalt, which is a name covering many varieties. They are common volcanic rocks and are thrown out now by the most active volcanoes. (5) The Peridotite Family, embracing pyroxenite, hornblendite, and, after alteration, the Serpentites.

The Sedimentary rocks are secondary formations. They are formed of the debris of the Igneous rocks as the latter have been worn away by the destructive agencies of the atmosphere and water, so that, having been laid down usually under water, they are almost always stratified, and are formed with rounded fragments rarely crystalline. The great bulk of the sedimentary materials consists of simpler and more stable compounds than the igneous minerals from the decomposition of which they have been derived.

The most useful classification of the sedimentary rocks is, primarily, according to the mode of their formation. This gives two principal divisions: I, the Aqueous Rocks, or those laid down under water; II, the Æolian Rocks,

Acidic → CLASSIFICATION → Basic

Surface Flows	Glassy	Acid Glasses Obsidian, Perlite, Pumice; Pitchstone			Andesite Obsidian					Basic Glasses, Scoriæ, Tachylite, Basalt Obsidian	
		Chief Felspar Orthoclase			Chief Felspar Plagioclase				Nepheline Leucite	No Felspar	
		Biotite and or Hornblende and or Augite			Biotite and or Hornblende		Pyroxenes			Augite and or Hornblende and or Biotite	
		+Quartz	−Quartz	Leucite Nepheline	+Quartz	−Quartz	−Olivine	+Olivine	−Olivine +Olivine	−Olivine	+Olivine
Surface Flows, Thin Sills, Dykes, Laccoliths	Glassy, Compact, or Porphyritic with few Phenocrysts	Rhyolite (Felsite, Quartz-Porphyry) Rhyolite-Porphyry	Trachyte (Felsite) Trachyte-Porphyry	Phonolite (rare) Leucite Rocks (Very rare) Phonolite-Porphyry	Dacite (Felsite) Dacite-Porphyry	Andesite (Felsite) Andesite-Porphyry	Augite-Andesite, Basalt (Diabase) Augite-Andesite-Porphyry	Olivine-Basalt, Olivine-(Diabase) Basalt-Porphyry	A series of Nepheline and Leucite Basaltic Rocks, very rare in America	Augitite Augitite-Porphyry	Limburgite Limburgite-Porphyry
Dykes, Sills, Laccoliths	Porphyritic with abundant Phenocrysts	Granite-Porphyry	Syenite-Porphyry	Nepheline-Syenite-Porphyry	Quartz-Diorite-Porphyry	Diorite-Porphyry	Gabbro-Porphyry	Olivine-Gabbro-Porphyry		Pyroxenite-Porphyry	Peridotite-Porphyry
Batholiths, Laccoliths	Granitoid	Granite	Syenite	Nepheline-Syenite, Leucite-Syenite (Very rare)	Quartz-Diorite	Diorite	(Diabase) Gabbro	(Olivine-Diabase) Olivine-Gabbro	Theralite (exceedingly rare)	Pyroxenite	Peridotite
	SiO_2	80–65%	65–55%	60–50%	70–60%	65–50%	50–45%		50–40%	55–30%	
		Granite fam.	Syenite family		Diorite family		Gabbro family			Peridotite family	

those which were accumulated on land, which are of more limited extent and importance. The rocks laid down under water form the larger and more important part of the sedimentary series.

From the accumulation of débris derived from the destruction of preëxisting rocks, carried in mechanical suspension by moving water, whether waves, currents or streams, and dropped when the velocity of the moving water was no longer sufficient to carry them, a certain group of the Aqueous Rocks has been formed. Such accumulations are forming to-day in all kinds of bodies of water, and an examination of the rocks will show that similar accumulations have been made since the beginning of recorded geological time. Mineralogically, the mechanical deposits are of two principal kinds, the siliceous and the argillaceous. The sorting power of water has been sufficient to separate them more or less completely. Sand, sandstone, gravel and conglomerate are in the siliceous group, and clay, mud, mudstone and shale are the Argillaceous Rocks.

The chemical precipitates are locally restricted, and not at all comparable to the great masses of mechanical and organic sediments. This arises from the fact that the chemical processes occur in a conspicuous way only around the mouths of certain classes of springs and in closed bodies of water without outlet and subject to evaporation. Thus calcareous tufa, oölite, gypsum and rock salt are alkaline, Geyserite and chert (flint) are siliceous, while bog and lake iron ore are ferruginous precipitates.

Limestone, shell marl, chalk, dolomite and green sand are calcareous accumulations, formed almost entirely by the accumulation of vegetable matter and its progressive tho incomplete decay under water. This decay is of such a nature that the gaseous constituents diminish while the carbon is removed much less rapidly; consequently the proportion of the latter substance steadily rises. All the varieties of carbonaceous rocks pass into one another so

gradually that the distinction between them seems somewhat arbitrary. From fresh and unchanged vegetable matter to the hardest anthracite there is an unbroken series of transitions. The three main divisions are peat, lignite or brown coal, and black coal.

Æolian Rocks form less of the earth's crust than do the aqueous rocks, but they have a special importance because of the hints which they often give as to the physical geography of the place and time of their formation. Blown sand, forming dunes, drift-sand rock, talus, soil and loess are all of Æolian origin.

Examined with reference to the simplest and broadest facts of structure, it will be noted that rock masses fall into two categories: (1) Stratified Rocks, and (2) Unstratified or Massive Rocks. The stratified rocks form more than nine-tenths of the earth's surface, and if the entire series of them were present at any one place they would have a maximum thickness of about thirty miles; but no such place is known.

As sedimentary strata were laid down upon one another in a more or less nearly horizontal position, the underlying beds must be older than those which cover them. This simple and obvious truth is termed the Law of Superposition. It furnishes the means of determining the chronology of rocks, and tho other methods of ascertaining this point are employed, they must all be based originally upon the observed order of superposition. "The only case," says Geikie, "in which the apparent superposition may be deceptive is when the strata have been inverted, as in the Alps, where the rocks composing huge mountain masses have been so completely overturned that the highest beds appear as if regularly covered by others which ought properly to underlie them. But these are exceptional occurrences, wherein the true order can usually be made out from other sources of evidence."

The stratified rocks which form the land have been changed, at least relatively, from the position which they

originally occupied, since the great bulk of them were laid down under the sea. Originally they must have been nearly horizontal, for this is a necessary result of the operation of gravity. Just as a deep fall of snow, when not drifted by the wind, gradually covers up the minor inequalities of the ground and leaves a level surface, so on the sea-bottom the sediments are spread out in nearly level layers, disregarding ordinary inequalities.

The displacements to which strata have been subjected after their formation are of two principal kinds: (1) In the first kind the strata have been lifted vertically upward, often to great heights, without losing their horizontality. In some of the lofty plateaus through which the Grand Cañon of the Colorado has been cut almost horizontal strata are found 10,000 feet above the sea-level. (2) More frequent and typical are the displacements of the second class, by which the beds are tilted and inclined at various angles.

The double condition of a semi-rigid crust with a fluid strata below, coupled with the phenomenon of cooling and contracting, renders the rocks of the earth susceptible to intensely heavy stresses, and breakage is inevitable, dislocation often occurring. But in all parts of the earth's surface the rocks are to be found in strata, so that when such a break occurs it interferes with the continuity of the strata. Where such is not the case, but the rock merely cracks open without any alteration of the levels of the various strata, it is called a 'fissure'; but when the strain has been vertical as well as horizontal (it is usually so), the result is to change the consecution of the strata. This is called a 'fault.'

"Whenever the rocks of the earth's crust are subjected to strain,' says J. E. Spurr, "fractures take place in them as in any other body under similar conditions, and the different parts of the rock tend to move past one another along the fracture-planes, seeking to obtain relief from the strain and to accommodate themselves to new condi-

tions. In this movement one part of the fractured rock-mass may move upon the other in any direction—up, down, sidewise or obliquely—according to the conditions, which are different in each instance."

The throw of faults varies greatly in different cases, from a fraction of an inch up to thousands of feet. In those of small throw the plane of fracture is frequently a clean, sharp break; but in the greater faults the rocks

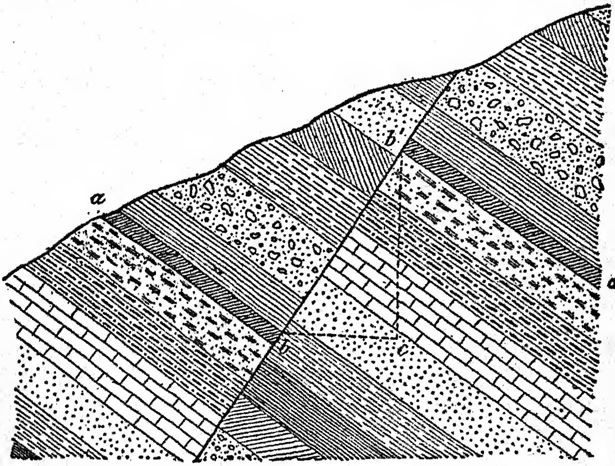


Fig. 27 —Fault at a.—b. Showing Superposition of Unlike Strata. (Scott.)

in the neighborhod of the fault are often bent, crushed and broken, forming a confused mass of fragments. In the present state of knowledge, however, any scheme of classification has an undue appearance of exactness.

Radial Faults are those in which the principal component of the movement has been upward, downward, or both, tho subordinate movements of tilting and rotation frequently occur. Normal Faults (also called gravity

faults) are those in which the fault-plane inclines toward the downthrow side, which forms the hanging wall. "It seems best to use the term normal," says J. A. Reid, "to cover those faults in which, using the horizontal plane as datum, the hanging wall has dropped relative to the foot." Strike-faults are those which run parallel or nearly so to the strike of the beds. Dip-faults are, in general, parallel to the dip of the beds, and therefore cross or branch out from the strike-faults of the same region, more or less at right angles; they are less important than strike-faults, having generally a smaller throw and less length. Dip-faults do not always follow the dip, and strike-faults often deviate considerably from the strike of the beds; and sometimes the fault is neither one nor the other, but midway between the two, and then is called an oblique fault. A reversed fault, which almost always coincides with the strike of the beds, implies a local compression, for the beds occupy less space than before dislocation.

In Horizontal Faults the principal direction of movement is horizontal, and in horizontal strata may readily escape detection. In faults of the preceding groups there is apt to be more or less rotation because of unequal friction and resistance of the walls, but in certain cases this movement of rotation is the principal one, exceeding any movement of translation; and these are the pivotal faults.

A thrust is like a reversed fault, in that it is the result of compression and that the inclination or hade of the fault is toward the upthrow side, which is the hanging wall, but differs in the tendency to a horizontal position of the plane of fracture and in the association with violent folding and plications. In his latest work on the subject B. Willis divides thrusts into the following three groups:

"Scission-thrusts are those in which the fault-plane is independent of any older structures, and occur chiefly in the crystalline schists (metamorphic rocks) and granite,

and, as a rule, depart but little from horizontality. Thrusts of this kind are developed on a great scale in the southern Appalachians, especially in eastern Tennessee, where thrusts of 20 miles or more have been observed. On an even more gigantic scale they occur in the Highlands of Scotland and Norway, where the movement of translation amounts to 75 miles.

"Fold-thrusts are intimately connected with folds, and occur only among folded sedimentary rocks; they may arise by plication and inversion, usually between an overturned anticline and the adjoining synclines.

"Surface-thrusts, as their name implies, are formed at the earth's surface, where a rigid, gently inclined stratum that crops out of the ground is subjected to lateral compression and thrust forward over the underlying beds."

The causes of crustal deformations are very obscure, and there is much difference of opinion concerning them. When strata are buried under a sufficient depth of overlying rock to crush them they become virtually plastic, and yield to the compressive force by bending. The movement would seem not to be a true molecular flow, but rather a gliding of the mineral particles one upon another. Geologists accordingly distinguish a shell of flowage, in which the rocks all yield plastically a more superficial shell of fracture, in which all but the softest rocks break on compression, and between the two a shell of fracture and flowage in which some rocks break and others bend, according to their rigidity. The depth of the zone of flowage is estimated at 20,000 to 30,000 feet below the surface.

One explanation made by Willis is that such phenomena are developed in regions that have been raised by upwarping above a position of adequate support, whence results a system of fractures and the settling and readjusting of the fault-blocks.

Quite a different type of explanation seeks to account for the phenomena of faulting by the transfers of molten

magmas deep within the earth. "Not only are the violent migrations of igneous material the cause of complex faulting," says J. A. Reid, "but also it is most reasonable to conceive that the deeper and more gradual movements of the subcrust are the cause of the larger fault systems. Given this cause of faulting, the heretofore puzzling facts are satisfactorily and easily explained. Compression and tension still remain true causes of faulting, but mainly as local and proximate ones. The common expression, tilting of fault-blocks, attains a deeper significance, for this tilting may be more largely the result of subcrust migrations than of mere force of gravity. Cases of horizontal motion and pivotal motion become simple, for there is no necessary unchangeable relation between the direction of the force and the position of the fracture-plane."

A modification of this hypothesis has been proposed by Professor Chamberlin, who regards the downward movements of segments of the earth's crust as primary and the horizontal movements as incidental to the former.

Rocks are not to be considered as unbroken solids, even the hardest and most compressed of them, for the reason that they are all interspersed with tiny crevices and sometimes larger cracks, which, as they bear a definite relation to the structure of the whole strata, are known as joints. Some of these, known as 'master joints,' extend immense distances below ground and form a natural beginning for quarrying stone, but there are usually also 'minor joints' as well. In igneous rocks this is obviously due to the contraction on cooling.

But there is a great deal of irregularity or 'unconformity,' as it is usually called, in the rocks themselves. Strata which have been laid down with but little interruption, which are parallel to the bedding places, and on which the movements of the earth's crust have operated in a uniform manner, show by their structure the comparative peace in which they have lain, and are said to be 'conformable'; but where two groups are found which

have been differently acted upon by reason of having been laid down in different periods, then these two groups are not conformable with each other, and their relation is known as 'unconformity.'

Volcanoes, like all other mountains, are subject to the destructive effects of the atmosphere, rivers, and the sea. In the Pacific States may be found admirable examples of volcanic cones in various stages of erosion, notably Mt. Shasta and Mt. Rainier. These mountains, however, merely exemplify the earliest stages of degradation; as time

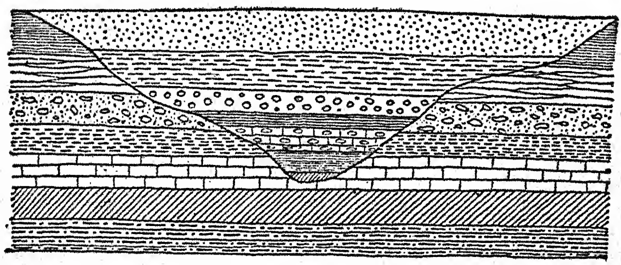


Fig. 28 —UNCONFORMITY, SHOWING SEDIMENTS LAID DOWN, ERODED AND NEW SERIES DEPOSITED.

goes on, the loftiest cones will be worn away, and at last only the worn-down and hardly recognisable stump of the volcano remains, which is known as a volcanic neck. The neck consists of the funnel or vent filled up with the hardened lava of the last eruption. The diamond mines of South Africa are in almost cylindrical pipes, which are cut through stratified rocks and are filled with an irregular agglomerate. On the surface the pipes show no topographical indication of their presence, but are quite level with the ground. Lava Flows and Sheets which were poured out on the surface of the ground may be recognised at a glance and traced to the vent whence they issued. Fragmental products are positive proof of volcanic action, for they cannot be formed underground.

The Plutonic Rocks form a series which no one has ever observed in the course of formation, because they were solidified at greater or less depths underground. Tho these unstratified masses cannot be observed in the process of formation, as may the lavas and pyroclastic rocks, yet the nature of the rocks themselves, and their relations to the volcanic and stratified rocks, afford a satisfactory explanation of themselves.

A primary division of the plutonic masses is into (1) injected and (2) subjacent bodies. "An injected body," says R. Daly, "is one which is entirely enclosed within the invaded formations, except along the relatively narrow openings to the chamber where the latter has been in communication with the feeding reservoir." Subjacent bodies, on the other hand, have no floor upon which the intrusive mass rests, the communication with the earth's interior being by great openings which enlarge downward indefinitely within the limits of observation.

Injected Bodies are of manifold variety of shapes and sizes, and differ in their relations to the enclosing or country rock, and different terms are accordingly used to describe them. A dyke is a vertical or steeply inclined wall of igneous rock which was forced up into a fissure when molten and there consolidated. Dykes of a certain kind may actually be seen in the making, as when the lava column of a volcano bursts its way through fissures in the cone.

Intrusive Veins are smaller and more irregular, frequently branching fissures which have been filled with an igneous magma; they may be only a few inches in thickness, and may often be traced to the mass which gave them off. Sills or Intrusive Sheets are horizontal or moderately inclined masses of igneous rock, which have small thickness as compared with their lateral extent. Sheets conform to the bedding-planes of the strata, often running long distances between the same two beds; but if they can be traced far enough they may generally be found

cutting across the strata at one point or another. In thickness they vary from a few feet to several hundreds of feet. The Palisades of the Hudson are formed by a sheet of unusual thickness; its outcrop is 70 miles long from north to south, and its thickness varies from 300 to 850 feet.

A laccolith is a large, lenticular mass of igneous rock, filling a chamber which it has made for itself by lifting the overlying strata into a domelike shape; the magma was supplied from below through a relatively small pipe or fissure. The rock of which laccoliths are made is nearly always of the highly siliceous and less fusible kinds, so that it can more easily lift the strata than force its way between them.

Batholiths are great masses of plutonic rock hundreds or even thousands of miles in extent; in general characteristics they agree with stocks, except for their very much greater size. Granite is the commonest batholitic rock, and in such masses forms the core of many great mountain ranges like the Sierra Nevada and the Rocky Mountains.

Much has been said of the manner in which rocks are cut down and built up again by the destructive agent of atmosphere and water, but there is another force which has led to the transformation of a rock from its original form, and this is known as Metamorphism. The term is somewhat vague, for so many factors enter into the making of metamorphic rocks, and the process took place so many aeons ago, that it is all but impossible to gain a clear conception of the manner in which they have come into being. An increase in hardness and in the degree of crystallization occurs, and not infrequently includes the generation of an entirely new set of minerals, characteristically arranged. Whether the original of the rock so metamorphosed was igneous or sedimentary cannot always be determined.

Metamorphism, as classified by Scott, is of two quite

distinct kinds: (1) Contact or local, and (2) regional metamorphism. "Contact metamorphism," he says, "is the change effected in surrounding rocks by igneous magmas. There is a difference between the effects produced by a surface lava flow and those caused by a plutonic intrusive. In the former case the results are usually not very striking because of the way in which a lava stream surrounds itself with non-conducting scoriæ, and are such as may be referred to the action of dry heat. Bituminous coal is changed into a natural coke by the removal of its volatile constituents; clay may be baked into a hard red rock looking like earthenware, and limestone changed to quicklime by driving off carbonic acid gas. Plutonic intrusions are more efficient agents of change, because they are presumably of a higher temperature and retain their heat longer, and because the vapors and gases which they contain cannot escape into the atmosphere but strongly affect the invaded rocks. The rock invaded and metamorphosed may be either sedimentary, igneous, or already metamorphic, and the effects may be very marked or surprisingly small; indeed, it is often quite impossible to say why the changes should be so insignificant. The distance to which the zone of change extends is wider when the intrusive mass cuts across the strata than when it follows the bedding-plane, so that a dyke or stock is more effective than a sill. Contact metamorphism, as its name implies, is a local phenomenon, but a widely ramifying and complex system of igneous intrusions may change large areas of sedimentary rocks.

"Regional or Dynamic Metamorphism applies to the reconstruction of rocks upon a great scale in areas covering, it may be, thousands of square miles, and evidently other processes in addition to those of contact metamorphism are needed to explain such widespread changes. Regionally metamorphic rocks are, with the exception of the slates, thoroly crystalline, and usually have lost all

trace of whatever fossils and stratification planes they may originally have had.

"The first step in metamorphism consists in a mere hardening of the rock, accompanied with the loss of water and other volatile substances. In the second stage the component minerals already present are crystallized, but new compounds are sparingly formed. This stage is frequently accompanied by cleavage, which, to distinguish it from that of minerals, is often called slaty cleavage."

"Cleavage," suggests C. R. van Hise, "is a capacity present in some rocks to break in certain directions more easily than in others, while fissility is a structure in some rocks by virtue of which they are already separated into parallel laminæ in a state of nature. The term fissility thus complements cleavage, and the two are included under cleavage as ordinarily defined." Ordinary roofing slate is one of the best possible examples of a cleaved rock, and in beds of slate interstratified with other rocks the cleavage is usually quite perfect in the former, absent or but partially developed in the latter.

The causes of metamorphism have been summarized by W. B. Scott as follows:

"1. Heat is evidently a very important factor of change, as is shown by the phenomena of contact metamorphism and by numerous experiments by which the process has been imitated successfully. In contact metamorphism the heat is derived from the igneous magmas, and in dynamic it is in part mechanically generated, in part due to the interior heat of the earth invading deeply buried masses.

"2. Compression is believed to be the great agent of dynamic metamorphism, and the amount of the change depends upon the intensity of the compression and the depth at which it operates. Hence the varying results, ranging from gentle folding at one end of the series through violent folding to complete reconstruction, crystallization and foliation at the other.

"3. Moisture is another potent agent of reconstruction.

Superheated water, under pressure, is able to attack and dissolve the most refractory substances and to build them up into new combinations. Many minerals, such as the felspars, which have never been artificially crystallized by dry heat alone, will crystallize readily in the presence of superheated water, and the water lowers the temperature necessary for metamorphism. Rocks which melt at 2,500° F. dry heat become pasty at 750° F. in the presence of water. In contact metamorphism steam is a very important factor of change, but other vapors and gases play an efficient part.

"4. Pressure, as distinguished from active compression, is a necessity for any extensive metamorphic action, whether contact or dynamic. It is the difference of pressure which is responsible for the different effects of surface flows of lava and of subterranean intrusions and which gives to depth its importance as a controlling factor. The dead-weight pressure of overlying rocks prevents the rapid escape of the mineralizing vapors, and when sufficiently great causes the rock to shear and flow without fracture. Limestone heated at the pressure of the atmosphere in a limekiln or an open vessel becomes quicklime through the expulsion of carbonic acid gas; but heated under pressure, so that the gas cannot escape, it crystallizes into marble. Such pressure also is an essential factor in dynamic metamorphism as a precondition in enabling the rock to behave more or less plastically under active compression and without shattering. Dynamic metamorphism must, therefore, take place at considerable depths below the surface."

The Non-foliated Rocks represent the less advanced stages of metamorphism, in which the forces of compression may have produced cleavage or fissility but not foliation.

The fissures, veins and faults which are to be found alike in Igneous, Sedimentary and Metamorphic rocks afford an excellent opportunity for the intrusion into the

rock of matter of a dissimilar character. Thus waters bearing mineral compounds in solution, passing over such crevice or fissure, might readily precipitate that which it bears, each tiny grain of precipitated mineral forcing out water at the top. Sometimes these veins are filled in again with the same form of matter as that of which the main rock is composed, but different in structure; sometimes the veins are filled by sediment which has been blown or washed in, and not infrequently fissures caused by earthquakes have been filled up from below by the intrusion of alien substances forced up by the interior pressure.

Fissures thus filled vary greatly in dimensions, from a few inches to many miles in length. The minute veins are filled with material derived from the walls by solution and redeposited in the crevices, such as the veins of crystallized calcite in limestone. Great fissure veins, on the other hand, which may run unchanged for many miles, and penetrate to depths beyond the reach of mining, are "characterized," says Spurr, "by regular, straight walls, by a fairly constant width, and by a definite direction of both strike and dip."

A third class of mineral veins is composed of the veins of replacement, in which the circulating waters have not merely deposited minerals in an open fissure but have gradually substituted one substance for another by dissolving out the latter and replacing it with the former, it may be molecule by molecule, so that the replacing minerals are pseudomorphs after the older series. A replacement vein represents a water channel of some kind, and so it has a more or less definite direction, but it seldom has sharply defined walls, for the new deposits impregnate the country rock and fade away into it. Replacement veins are most commonly found in limestones, since those are the most readily soluble rocks, but they also occur in rocks which are relatively very insoluble, such as sandstones, and in igneous rocks like granite.

Frequently the ores of the commercially valuable metals

are found in mineral veins, which then are called metalliferous veins.

"Structural geology," says W. B. Scott, in summarizing up the questions relative to the formation of the rocks, "brings vividly before one the innumerable changes through which the earth's surface has passed and which are recorded in the rocks. The sedimentary rocks, originally laid down under water in approximately horizontal positions, have been upheaved into land surfaces, either without losing that horizontality, or being tilted, folded, compressed, or even violently overturned. Or they may be fractured and dislocated in great faults and thrusts. These movements have been found to be due to enormous lateral compression set up within the crust of the earth, a compression generated in some manner not yet clearly understood. Whether folding or faulting shall result from a given compression depends upon the rigidity of the strata, upon the load which overlies them, and the sudden or gradual way in which compression is applied. The results of compression on a large scale are accompanied by certain minor changes not less characteristic. Compressed rocks are cleaved, fissile or schistose, according to the intensity of the action and whether the rocks affected are in the shell of flowage or of fracture. These changes may go so far as completely to reconstruct the minerals of the rocks, destroying the old, generating new, and obliterating the original character of the strata. Thus displacements, dislocations, cleavage, fissility and dynamic metamorphism are but the varying results of lateral compression acting under different conditions and at varying depths.

"Another class of rocks—the igneous, massive or unstratified—were found to have penetrated and overflowed the strata and to have consolidated in the fissures and cavities which they have made for themselves, or to have been poured out freely on the surface. According to the circumstances under which these masses have cooled the

resulting rock is of glassy, porphyritic, finely or coarsely crystalline texture. When solidified as sheets or dykes the igneous rocks may be folded, faulted, cleaved or metamorphosed like the strata, and when a region has been long and repeatedly subjected to compression its structure may become excessively complex and the metamorphosis of its rocks so complete that not even the most careful examination will suffice to distinguish those rocks which were originally sedimentary from those which were igneous.

"Highly heated waters circulating through fissures and along the joint-planes of the rocks deposit the substances which form the mineral and metalliferous veins, tho concerning the source of these substances and of the solvent waters there is much difference of opinion. Our study has taught us that many of these processes go on deep within the earth's crust, and hence cannot be directly observed, but must be inferred from their results. Encouraging progress has already been made in this work, but very much more remains to be done before a knowledge of structure and its full meaning shall be even approximately complete."

CHAPTER XII

YOUR OWN NEIGHBORHOOD

Around every man spreads some horizon, either made by man or made by Nature, and this horizon is the alphabet of the book of his environment. The jagged carvings of the Bad Lands of Dakota, the unbroken circle of the prairies of Nevada, the deep clefts of the mountains of Tennessee, or the rounded slopes of the rolling country of Central New York—one has but to glance around each of these to read the first chapter of the story of the land on which the beholder stands.

There is a certain spell and homelikeness in the words "Your Own Neighborhood." It stands for something so familiar, often so well-loved. Sometimes, however, it stands for something too familiar, something to which we have grown too well accustomed, out of which we feel that we have sucked all the worth, into which we feel no new thing can ever come.

Nothing could be further from the truth. We have not read all the story, we simply have not known of the thousands of stories that our own neighborhood could tell. And, since every neighborhood has stories of its own to relate, it follows that in pointing them out, the writer can only give hints as to where they may be found. The dweller in that neighborhood shall find them out for himself.

"I will lift up mine eyes unto the hills, whence cometh my help," are words that might have been penned by a

geologist. He lifts up his eyes to the hills, and, as he looks, out of the distant past come trooping the ghosts of mountain ranges long since dead, and of oceans filled with strange reptiles that no man ever saw alive—though their skeletons litter America. He sees some scratches on the surface of a boulder, and before him, as of old, the mighty glaciers of the Ice Age come crushing down, driving before them in headlong confusion a motley horde of mammoth and rhinoceros, cave-bear and sabre-tooth tiger. He sees, among these, the shrinking form of early man, and remembers how his bones have been found mixed with their bones in the great glacial deposits.

He stoops and picks up a pebble. It is a piece of flint, a compact form of quartz, and it brings before him all the other forms of quartz—the onyx, rock-crystal or the amethyst, and his mind goes back to the early days of the world when quartz was a-making. How small a difference in the story, then, would have made this common piece of flint an amethyst of great price!

Is the region in "Your Own Neighborhood" gently rolling, with hills with softly rounded crests? Then it is immeasurably old. You are a child of a region that has sunk into the sleep of quiet, and your neighborhood antedates by tens of millions of years the upstart neighborhoods of the far west. Do the little streams and rivers in your neighborhood flow with a shallow stream and a gentle current? Theirs, too, is the quiet of age. Suppose, however, they run with deeper banks and swifter streams; suppose, even, they have a sort of canyon through which they flow; then you may know that they are not underlaid by the granite of an older time, but by some sedimentary rock that not so long ago was the bed of a ghost-like ocean where monstrous reptiles sprawled.

Is "Your Own Neighborhood" in New England? Then read the story of the granite, the grey, gaunt ancestor of rocks, and see if there is not pride in its sturdy defiance of the ravages of time, when the rocks of yesterday—the

sandstones—as in the Garden of the Gods, in Colorado, are melting away like snow under the summer sun.

Is "Your Own Neighborhood" in the Catskills? Look at their long, flowing lines, the valleys that lie so snugly embosomed among them, and you will feel the spell of quiet and of rest. Hills of erosion, these, worn down to roundness by the hand of time. Your home, whether on the hillside or in the valley, lies at least two thousand feet below the original surface of a tableland, which, in Devonian times, stretched an unbroken expanse at least as high above the highest points of the Catskills as that point today is above the level of the sea. But, if you like to read the story, the topography of your own neighborhood will go back farther still, and show you, bit by bit, what happened in the days before even that Devonian tableland was built.

Is "Your Own Neighborhood" in the northern middle states? Then is the movement of the Ice Age part of your story. It is not so long ago—as the geologist counts time—that all the northern middle states were in the same condition as Greenland is today. The great Polar Ice-cap ran along a line stretching (approximately) from Trenton, N. J., to St. Louis, and thence to Omaha and the Yellowstone. In more recent times still, great glaciers flowed over the regions which are now the heart of America's dairying industry. The glaciers are not all gone; Mount Rainier, Wash., has some still; Glacier National Park has a number of them.

Is "Your Own Neighorbood" in any part of the great Appalachian chain? Very different is its story. These mountains are made of rocks laid down at the bottom of the sea in Paleozoic time. Twenty-five thousand feet were laid down under the water, and then, in a convulsion of the earth, the crust was squeezed and the mountain range thrust forth. What were the rocks laid down under the sea? What were the creatures living in that sea? If you would read that story, it lies around you in

a thousand stones and boulders, sandstones and limestones, organic and inorganic rocks, ready to reveal the tale to anyone who takes the trouble to turn the pages.

Is "Your Own Neighborhood" in the alluvial plains of the South? Think of the Mississippi valley and of the great rivers of the past. Look at the soil of the "black belt" or the "red earth" of Georgia. There the book is not only written in plain type, but brilliantly colored. And, if you would see how the world is always being made anew, see how each year the Mississippi is carrying the soil from Ohio and the other states within its basin, and, of that mud, making at its delta a new land that juts far out into the Gulf of Mexico. In course of time it may fill the Gulf, and the West Indies may be a range of hills around a great fertile plain. The region will pass through the swamp stage first, like the Everglades of Florida, which are midway on their passage from sea to land.

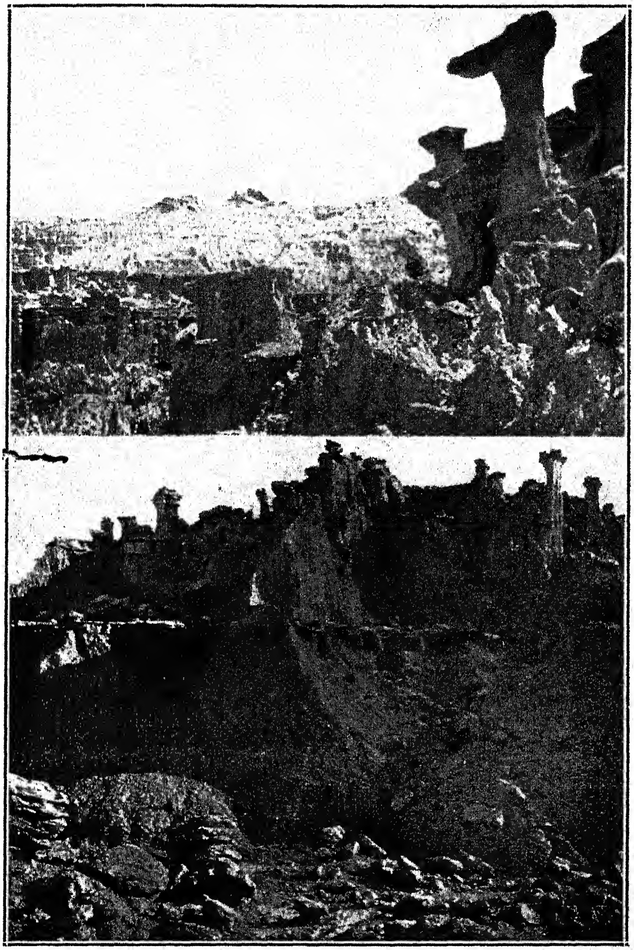
Is "Your Own Neighborhood" on the plains? Or in the Rocky Mountains? Or in the Sierras? Then the story hardly needs to be pointed out, it is so simply told. For these are the "newly rich" of geologic time. They are more recent than the Alps, than the Himalayas, which also—like the Appalachians—were nursed in the cradle of the Tertiary Seas. Frail creatures, too, these western mountains, soft and friable. They are still rising, slowly, but they wear away even faster. The old rocks abide longer. The Cretaceous or chalk formations, the limestones, speedily melt away. See how limestone-underlaid Kentucky is undermined with caves!

Suppose we take the earth as 365 million years old, and consider this period as a year, one million years being taken as a day. Then the Appalachians were raised in September, the Sierra Nevada toward the end of October, the Rocky Mountains during December. On such a scale the whole period of Man is not likely to have been further back than the evening of December 31st, the earliest

historic evidence (in Egypt) is not more than ten minutes before the last midnight, and it is, in comparison with the years of the world's age, less than five minutes' interval between our own times and the days of Moses.

Nor is it to be supposed that the phrase "Your Own Neighborhood" necessarily implies in geology a section as large as New England. It may be as large or as small as one wishes. Pick up a piece of rock from New York City and a piece from Hoboken, just across the Hudson River. New York shore is tens of millions of years the older; the rock you have picked up is part of the old Archæan rock-bottom of the world. On the Jersey shore the famous Palisades are Triassic, between the Appalachian and the Sierras, or, using our former time scale, in the end of September or the beginning of October of that vast Earth-Year. The New York rock antedates the first life upon this planet, the Jersey rock is marked with impressions of the feet of the giant reptiles. Take even so small a piece of land as Staten Island. Here, within a space of ten miles, is land that was once under the ice-cap; land strewn with the boulders of the moraine, scratched and marred; and land that the ice never reached. One part of the Atlantic coast shows where the sea is creeping in, another where the land is creeping out. In other places are old forests now under a lake bed, elsewhere are lake beaches hundreds of feet above the water. This farm lies on clay, the next on gravel, the third on shale. Each has a different story.

Take an ordinary claw-hammer and crack the first dozen stones you find near your house. This one is granite, and tells its tale of fire. You see in it the quartz, felspar and the mica. If you could break the crystals of quartz, you would find them cleave like glass, but if you try to break the mica it will divide into leaves like the thinnest tissue paper, but flexible and elastic. The little crystals of felspar, too, from the decomposition of these comes kaolin or the china-clay, from which fine china is



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SOUTH DAKOTA BAD LANDS. EROSION OF SANDSTONE AND CLAY DEPOSITS.

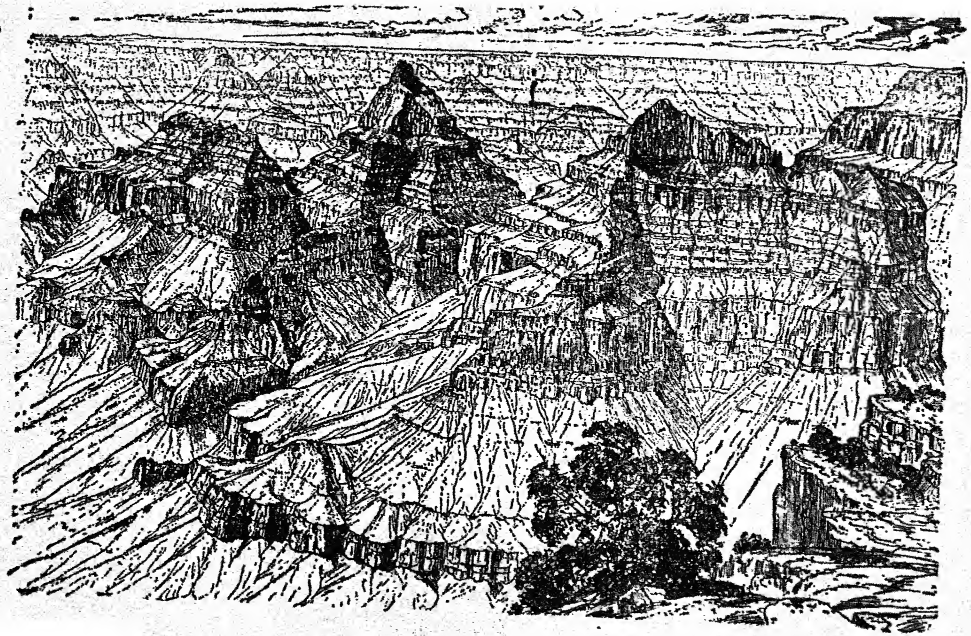


Fig. 29 —Grand Cañon of the Colorado.
Example of Erosion by Water and Weather, Showing Varying Hardness of Different Strata.

made. All these stories in a granite pebble! And still nothing has been said of all the kinds of granite, all the colorings, gray, green, pink and red. Yet every tint is a clue to a further story still.

Your next stone may be a piece of chalk. Look at this closely and you shall see the sea shells of which it is made, for chalk is but the cemetery of untold billions of tiny sea creatures whose shells, after they died, sank to the ocean floor. Beside this may be found a piece of slate, which is a rock made of clay, hardened by compression. There are dozens of different kinds of slates. Like the sandstones, the slates are composed of an endless variety of other rocks, and in them, also particles of quartz and scales of mica may be seen.

Every neighborhood has its own rocks and pebbles, and these tell a story fully as wonderful as the vaster book of the scenery of hill and valley. Cut these pebbles into thin slices, examine them under a microscope—a scientific study within the means of every one—and a new world opens. Here is a story that the world so far has only partly read. It is a fascinating study, which may be carried on in a city apartment, a suburban home or a farmhouse kitchen as readily as in a well-equipped geo-physical laboratory. If to this be added simple experiments on crystallization, the field of wonder grows to the point of entrancement.

This study of one's own neighborhood, or physiography, is becoming an important branch of Geology. It has been suggested that this subject treated from the geological side should be called Geomorphogeny, since the geologist makes use of the topography to determine the nature of the changes, while the physical geographer employs the conception of changes to explain the topography. It will be seen immediately how the two subjects interlock, but none the less there is a quite different principle involved.

The questions involved in Geomorphogeny, then, are those of aggradation, or the elevation of the land, and

diastrophism, the removal of land in one place for the purpose of building it up in another. A third class of factors, which, however, are passive rather than active, are the character, arrangement and attitude of the rock masses. A partially degraded region in which the rocks are homogeneous will have a very different kind of relief from one in which the rocks are heterogeneous and differ materially in their powers of resistance to the denuding agents.

The topography of any region is the resultant of the very complex interaction of many different kinds of factors and is subject to continual change according to definite laws. Suppose, in the first instance, a region newly upheaved from beneath the sea into dry land. The topography of such an area will be constructional, due entirely to the processes of diastrophism and accumulation and characterized by the absence of a highly developed system of drainage by streams. The coastal plain of the middle and southern Atlantic States is an example of such topography but slightly modied.

Next, the processes of denudation begin their work upon the region. The sea attacks the coast-line by cutting it back in one place and building it out in another until a condition of equilibrium is attained. Rivers are established, adjusting themselves to the structure of the underlying rocks and cutting deep, trench-like valleys, while the atmospheric agencies widen out the valleys, slowly wearing down and washing away the sides and tops of the hills.

A river has its stages of development, youth, maturity and old age, just as has a land surface, each stage displaying its characteristic marks. In a newly upheaved or newly folded land the streams are determined entirely by the slopes of the new surface and are called consequent streams. As the river system becomes somewhat older, the stream channels are deepened, the larger ones being cut down to base-level, and if the region be one of con-

siderable elevation, deep gorges and cañons are excavated. A mature river system is characterized by the complete development of its tributaries and drainage, so that every part of its basin is reached by the ramifying channels. Valley floors are broadened and deposition begins upon them, and the streams, reaching a condition of equilibrium between erosion and deposition, are said to be graded.

The final stages of river development are reached when the base-level is attained and the drainage basin reduced to a peneplain by the combined action of the streams and weathering.

As a river system approaches maturity it will increase the number of its branches, and those branches which were not at all represented in the youthful stages of the system and are opened out along lines of yielding rocks are called subsequent.

However the streams of a district may have been established in the first instance, whether they were consequent, antecedent or superimposed, they are liable to changes more or less profound and far-reaching. The up-stream extension of branches and the shifting of divides result in the capture of streams, or parts of such, by others more favorably situated, one master stream gradually absorbing many smaller ones which had originally been independent.

Fig. 30 shows two stages in the evolution of a river system. Fig. 31 represents the first stage, in which several transverse streams, a, c, e, f, g, are breaching the escarpments indicated by shaded lines. Of these streams, c carries the most water and will therefore deepen its gorges through the hard ridges more rapidly than the others and give its tributaries the advantage of a greater fall. In the second stage, c has captured the upper courses of all the other streams except g, which has not yet been reached. The branch l has captured a, beheading it, diverting the portion a″ and reversing the portion a′. Similarly m has captured and divided e; n has done the same with b and p with d, while g must eventually suffer the same fate.

Wind-gaps will be left in the ridges where the captured streams once crossed them.

Coast-lines also are of great physiographic importance. There is no greater mistake than to suppose the seacoast to be merely a line whereat the sea now washes. Yet it would be easy to find many people who would define the seacoast as being that stretch of land between high-water and low-water mark, with perhaps the addition of the former beach (in some cases), to the point of the beginning of land vegetation. Yet the coast line, truly speaking, may

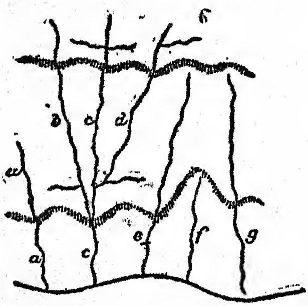


Fig. 30 —Evolution of River System. First Stage.

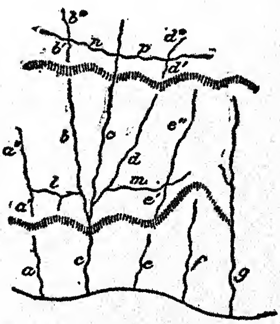


Fig. 31 —River System. Second Stage.

extend a long distance under the sea, and in similar wise a wide range of marine beach formation may exist on land, even miles away from the sea.

"Regular coasts," says A. Penck, "continue for great distances without notable indentations and, for the most part, in gentle curves, convex toward the land, which are connected by curved lines or meet at obtuse angles. The flatter the coast, the more perfectly is this type developed, and the coast line runs for many kilometers in the same curve. With a steep slope the course is regular

only in general; in detail it seems as tho drawn by a trembling hand, with numerous little prominences, which project but a few hundred meters beyond the general coast line and separated from one another by shallow, curved indentations."

The most conspicuous example of the irregular coast unquestionably is the fjord, seen in Norway and Scotland. They are irregular to a wonderful degree, possessing only this in common that they are produced by the depression and submergence of land surfaces, not by the throwing up of the high bluff, cliffs and crags that remain. The fjords are long, narrow, frequently branched and usually very deep.

The ridges of land which separate adjoining fjords are frequently notched by low passes, which seaward become straits, connecting the fjords and cutting up the ridges into islands, which are always very numerous along coasts of this class. The famous "inside passage" from Puget Sound to Sitka, Alaska, is a network of deep waterways among countless islands. What are termed Rias Coasts have frequently been regarded as fjord coasts, but the bays here are shorter, more funnel-shaped and not nearly so deep as fjords. Moreover, they are not of glacial origin and hence are more widely distributed.

Calas Coasts are marked by numerous short, semi-circular and rather shallow bays, separated by narrow peninsulas and owe their irregularities not to wave erosion, but to the submergence of land valleys; those of the typical kind are due to the depression of mountain slopes, furrowed by numerous short ravines.

Faults are probably the cause of deep lobate coasts, such as are to be found in Greece and in Hayti and Japan. There the bays are not so much irregularities in the coast line as deep gulfs, which have taken into themselves hundreds of square miles of land surface and where the interlocking gulfs are of the same order of magnitude.

The popular use of the word 'mountain' is another snare.

For example, there are many so-called mountains which are nothing more than the tops of the original plain, the whole of the surrounding country having sunk. A well-known example of this is the Grand Cañon of the Colorado, where, altho there are cliffs and buttes of immense height from their bases, yet a line from side to side of the great gorge will reveal that none are greatly higher than the surface of the plain from which the river has cut itself down. Some so-called mountain peaks and ridges are merely the portions of dissected plateaus left standing, such as Lookout Mountain and Missionary Ridge in Tennessee and the Alleghany Front in Pennsylvania.

A mountain range is made up of a series of more or less parallel ridges, all of which were formed within a single geosyncline or on its borders. The Appalachian range, the Wasatch, the Coast Range are examples of typical mountain ranges. A mountain system is made up of a number of parallel or consecutive ranges, formed in separate geosynclines, but of approximately similar dates of upheaval. The Appalachian system comprises the Appalachian range, running from New York to Georgia; the Acadian range in Nova Scotia and New Brunswick, and the Ouachita range in Arkansas. Each of these ranges was formed in a different geosynclinal, but at the same geological date, and they are consecutive, having a common direction. A mountain chain comprises two or more systems in the same general region of elevation, but of different dates of origin. The Appalachian chain includes the Appalachian system, the Blue Ridge, the Highlands of New Jersey and the Hudson, a system of different date, and the Taconic system of western New England, which was not formed at the same time as either of the others. A cordillera consists of several mountain chains in the same part of the continent. Thus the chains of the Rocky Mountains, Sierra Nevada, Coast Range and their prolongations in Canada together make up the Rocky Mountain or Western Cordillera. From these definitions it will appear that

the mountain range has a unity of structure and origin which fits it especially for study. If the history of the ranges be understood, the systems and chains will offer little additional difficulty.

The manner in which mountain ranges have been formed must be deduced from a careful study of their structure, for no one has ever witnessed the process of that formation. Mountain building may be going on at the present time; indeed, there is no reason to suppose that it is not, but so slowly is the work carried on that it withdraws itself entirely from observation. Nevertheless the general course

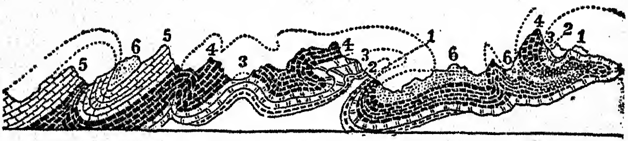


Fig. 32 —PROFILE OF JURA MTS., SWITZERLAND; THE FAULT, THE FOLD AND THE THRUST.

of events may be inferred with much confidence from the structure of the range.

The first step in the formation of a mountain range must evidently be the accumulation of an immensely thick body of strata. This, of course, must have taken place chiefly under shoal water, as thick strata can be accumulated only in rather shallow water and parallel with shore lines. To accumulate thick strata in shoal water, the bottom must subside as the sediments are piled upon it, else the water would be filled up and deposition cease. Such a sinking trough is a geosyncline, and in geosynclines filled with sediments is the cradle of the mountains.

The second stage in the building of a range is the upheaval of the thick mass of strata into a series of folds. This can be produced only by lateral compression, a conclusion which is sustained not only by the mechanics of folding and faulting, but also by the less obvious struc-

tures, such as cleavage and fissility, metamorphism, the microscopic crumplings and plications and the crushing and flowage of the mineral particles. The compressing force does not raise anticlines with great cavities beneath them, for such arches could not well be self-supporting, but mashes together the whole mass of strata, raising them into folds and wrinkles, crowding the beds into a greatly reduced breadth; or, when they are not sufficiently loaded to be plastic, breaking and dislocating them in great thrusts. It is not necessary to suppose that a mountain range was thrown up by one steady movement. On the contrary, there is good reason to believe that repeated movements, separated, it may be, by long intervals of time, have been engaged in the work.

There are certain mountain ranges which have a different structure and must have had a correspondingly different mode of origin. As already pointed out, in the Great Basin, which lies between the Sierra Nevada and the Wasatch Mountains, are a number of parallel mountain ranges with a prevalent north and south trend, which are collectively called the Basin Ranges. These mountains are not folds of very thick strata, but tilted-fault blocks, which have been made by normal faults, each upthrow side standing as a great escarpment, but with a tilted top that gradually slopes back to the foot of the next block, to which it stands as the downthrow side. The processes of denudation have carved these tilted blocks into peaks and ridges of the ordinary kind. Every mountain range has been profoundly affected by the agencies of denudation, and their ridges and peaks, their cliffs and valleys have been carved out of swelling folds and domes or angular, tilted fault-blocks.

"The general character of the structure of the American continent is extreme simplicity," says Geikie, "as compared with that of the Old World. In part of the Rocky Mountain region, for example, while the Paleozoic formations lie uncomfortably upon pre-Cambrian gneiss, there is, ac-

cording to King, a regular conformable sequence from the lowest Paleozoic to the Jurassic rocks, tho probably many

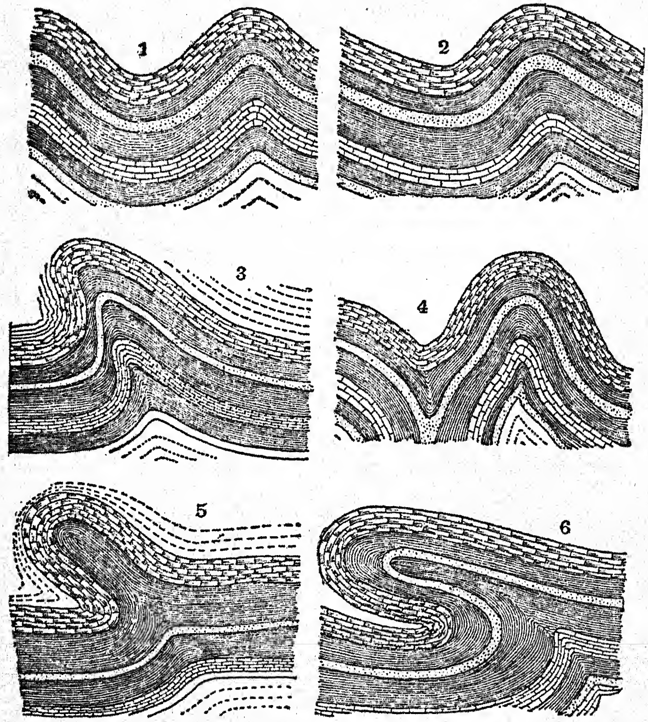


Fig. 33 —DIAGRAM OF FOLDS.

1., Symmetrical Open Fold; 2., Asymmetrical Open Fold; 3., Asymmetrical Closed and Overturned Fold; 4., Symmetrical Closed Fold; 5., Closed Overturned Anticline; 6., Closed Recumbent Anticline. (Willis.)

local unconformabilities exist. During the enormous interval of time represented by these massive formations,

what is now the present axis of the continent appears to have been exempt from any great orogenic paroxysm and to have remained hardly disturbed by more than a gentle and protracted subsidence.

"In the great depression or geosyncline thus produced all the Paleozoic and a great part of the Mesozoic rocks were accumulated. At the close of the Jurassic Period the first great upheavals took place. Two lofty ranges of mountains—the Sierra Nevada (now with summits more than 14,000 feet high) and the Wahsatch—400 miles apart, were pushed up from the great subsiding area. These movements were followed by a prolonged subsidence, during which Cretaceous sediments accumulated over the Rocky Mountain region to a depth of 9,000 feet or more. Then came another vast uplift, whereby the Cretaceous sediments were elevated into the crests of the mountains, and a parallel coast range was formed fronting the Pacific.

"Intense metamorphism of the Cretaceous rocks is stated to have taken place. The Rocky Mountains, with the elevated table land from which they rise, now permanently raised above the sea, were gradually elevated to their present height. Vast lakes filled depressions among them, in which, and on the plains in front of the mountains, as in the Tertiary basins of the Alps and the Gondwana series of the Himalaya, enormous masses of sediment accumulated. The slopes of the land were clothed with an abundant vegetation, in which we may trace the ancestors of many of the living trees of North America. One of the most striking features in the later phases of this history was the outpouring of great floods of trachyte, basalt and other lavas from many points and fissures over a vast space of the Rocky Mountains and the tracts lying to the west. In the Snake River region alone the basalts have a depth of 700 to 1,000 feet over an area 300 miles in breadth."

CHAPTER XIII

READING THE LIFE OF THE PAST

WHILE the life-history of organisms is truly biology and the life-history of extinct forms of animals belongs largely to paleontology, yet the geologist has an intimate relation to both—to the life-history of present organisms because of their effects upon the earth's surface and to the relics of past organic life because their presence in certain rocks reveals the conditions that prevailed when those rocks were laid down.

"Historical geology," says Geikie, "deals with fossils or organic remains preserved in natural deposits and endeavors to gather from them information as to the history of the globe and its inhabitants. The term fossil, meaning literally anything 'dug up,' was formerly applied indiscriminately to any mineral substance taken out of the earth's crust, whether organized or not. Ordinary minerals and rocks were thus included as fossils.

"For many years, however, the meaning of the word has been so restricted as to include only the remains or traces of plants and animals preserved in any natural formation, whether hard rock or loose superficial deposit. The idea of antiquity or relative date is not necessarily involved in this conception of the term. Thus the bones of a sheep buried under gravel and silt by a modern flood and the obscure crystalline traces of a coral in ancient masses of limestone are equally fossils.

"Nor has the term fossil any limitation as to organic

grade. It includes not merely the remains of organisms, but also whatever was directly connected with or produced by these organisms. Thus the resin which exuded from trees of long-perished forests is as much a fossil as any portion of the stem, leaves, flowers or fruit, and in some respects is even more valuable to the geologist than more determinable remains of its parent trees, because it has often preserved in admirable perfection the insects which flitted about in the woodlands. The burrows or trails of a worm, in sandstone or shale, claim recognition as fossils, and indeed are commonly the only indications to be met with of the existence of annelid life among old geological formations. The droppings (coprolites) of fishes and reptiles are excellent fossils, and tell their tale as to the presence and food of vertebrate life in ancient waters. The little agglutinated cases of the caddis-worm remain as fossils in formations from which perchance most other traces of life may have passed away. Nay, the very handiwork of man, when preserved in any natural manner, is entitled to rank among fossils, as where his flint implements have been dropped into the prehistoric gravels of river-valleys or where his canoes have been buried in the silt of lake-bottoms.

"The term fossil, moreover, suffers no restriction as to the condition or state of preservation of any organism. In some rare instances the very flesh, skin and hair of a mammal have been preserved for thousands of years, as in the case of mammoth carcasses entombed in the frozen mud-cliffs of Siberia. Generally, all or most of the original animal matter has disappeared and the organism has been more or less completely mineralized or petrified. It often happens that the whole organism has decayed and a mere cast in amorphous mineral matter, as sand, clay, ironstone, silica or limestone, remains; yet all these variations must be comprized in the comprehensive term fossil."

"The conditions of the preservation of fossils," says Scott, "are much more favorable to some kinds of organ-

isms than to others. It is only under the rarest circumstances that soft, gelatinous animals, which (like jellyfish) have no hard parts, can leave traces in the rocks. The vast majority of fossilized animals are those which have hard shells, scales, teeth or bones; and of plants, those which contains a sufficient amount of woody tissue. Again, the conditions under which organisms live have a great influence upon the chances of their preservation as fossils. Land animals and plants are much less favorably situated than are aquatic forms, and since the greater number of sedimentary rocks were laid down in the sea marine organisms are much more common as fossils than are those of fresh water.

"On land fossils have been preserved, sometimes in astonishing numbers, under wind-made accumulations of sand, dust or volcanic ash and in the flood-plain deposits of rivers. Peat bogs are excellent places for fossilization, and the coal seams have yielded great numbers of fossils, principally of plants. The remains of land animals and plants, especially of the latter, are sometimes swept out to sea, sink to the bottom and are there covered up and preserved in the deposits; but such occurrences are relatively uncommon. Small lakes offer more favorable conditions for the preservation of terrestrial organisms. Surrounding trees drop their leaves, flowers and fruit upon the mudflats, insects fall into the quiet waters, while quadrupeds are mired in mud or quicksand and soon buried out of sight. Flooded streams bring in quantities of vegetable débris, together with the carcasses of land animals drowned by the sudden rise of the flood.

"The great series of fresh-water and volcanic-ash deposits, which for long ages were formed in various parts of our West, have proved to be a marvelous museum of the land and fresh-water life of that region. On the fine-grained shales are preserved innumerable insects and fishes, with multitudes of leaves, many fruits and occa-

sionally flowers, while in the sands, clays and tuffs are entombed the bones of the reptiles, mammals and, more rarely, birds of the land, mingled with those of the crocodiles, turtles and fishes that lived in the water. Similar deposits are known in other continents. But it is on the sea-bed that the conditions are most favorable to the preservation of the greatest number and variety of fossils. Among the littoral deposits ground by the ceaseless action of the surf fossils are not likely to be abundant or well preserved, but in quieter and deeper waters vast numbers of dead shells and the like accumulate and are buried in sediments."

"A geological chronology," says Scott again, "is constructed by carefully determining, first of all, the order of superposition of the stratified rocks and next by learning the fossils characteristic of each group of strata. To many it has seemed that this is reasoning in a circle, but that is because the argument is not fully stated, some of its steps being omitted. The order of succession among the fossils is determined from the order of superposition of the strata in which they occur. When that succession has been thus established it may be employed as a general standard.

"Great physical events, such as the upheaval of mountain ranges, widespread transgressions of the sea and changes of climate, often provide a means of correlating the strata of different continents with greater precision than can be done with the aid of fossils only. The latter are, however, indispensable means of first determining which of these events are comparable in different regions. The history is recorded partly in the nature and structure of the rocks, partly in the fossils and partly in the topographical forms of the land and the courses of the streams. By combining these different lines of evidence, local histories are constructed for each region, until from these the story of the whole continent may be compiled. The comparative study of the fossils then gives the clue for uniting

the history of the different continents into the history of the earth.

"The method of making the divisions and subdivisions of geological time is not yet a fixed one, and there is much difference in the usage of various writers. The names of the divisions also have been given at various times and in many lands, according to no particular system. Most of these names have been taken from the locality or district where the rocks in question were first studied or are most typically displayed, as Devonian from Devonshire, Jurassic from the Jura Mountains. Some are named from a characteristic or prevalent kind of rock, such as Cretaceous (Latin 'creta,' chalk) and Carboniferous. Of late there has been a tendency toward a more uniform method of nomenclature, and to the use of one set of terms for the divisions of time and another and corresponding set for the divisions of the strata. The following table represents the divisions in the scale of time and the scale of rocks which have been adopted by the International Geological Congress:

TIME SCALE	ROCK SCALE
Era	Group
Period	System
Epoch	Series
Age	Stage
	Substage
	Zone

"It will be observed that the subdivision is carried farther in the scale of rocks than in that of time, because of the generally local character of these minor subdivisions. The names employed are, as yet, the same for both scales, and we speak of the Paleozoic Era or Group and of the Silurian Period or System. It has been proposed to give separate names to the divisions of the two scales, and this would be an improvement in some respects.

TABLE OF MAJOR GEOLOGICAL DIVISIONS

Cenozoic Era	Quaternary Period
	Tertiary Period
Mesozoic Era	Cretaceous Period
	Jurassic Period
	Triassic Period
Paleozoic Era	Permian Period
	Carboniferous Period
	Devonian Period
	Silurian Period
	Ordovician Period
	Cambrian Period
Pre-Cambrian Eras	Algonkian Period
	Archæan Period

"Tracing the history of mankind back to very ancient times, records become more and more scanty and less intelligible, until history fades into myth and tradition. Of a still earlier age there is not even a tradition; it is prehistoric. Similarly among the geological records the earliest are in a state of such excessive confusion that they are exceedingly difficult to understand, and between different observers there are radical differences of opinion both as to the facts and as to their interpretation. Furthermore, they must have been an inconceivably long time earlier than the most ancient recorded periods, as to which conjecture and inference are the only resource. In these difficult straits astronomy offers valuable assistance to the baffled geologist. The Nebular Hypothesis is a scheme of the development of the solar system which is generally accepted by astronomers in some form as essentially true.

"The term nebular hypothesis is usually, tho not with exactness, limited to one particular form, according to which the place of the present solar system was originally occupied by a vast rotating nebula, a mass of intensely heated vapor, or possibly clouds of meteorites, extending

beyond the orbit of the outermost planet. As the nebula cooled by radiation, it contracted, leaving behind it successive rings, like those of the planet Saturn, but on a vastly larger scale. The rings kept up the rotation imparted by the nebula and all of them lay in nearly the same plane. Unequal contraction in various parts of each revolving ring caused it to break up and gather by mutual attraction into masses. If these rings were composed of relatively small solid masses, like meteorites, or if they had solidified by condensation of the vapors, the heat generated by the collision, as the broken ring was gathered into a mass, would suffice to raise the temperature and liquefy or vaporize the mass. By revolution the nebulous masses would assume a spheroidal shape and become planets. The central mass of the original nebula forms the sun, which is still in an intensely heated, incandescent state."

Another form of the nebular hypothesis, called for the sake of distinction the Planetesimal Hypothesis, has recently been proposed by Professor Chamberlin. This postulates, as the beginning of the solar system, a spiral nebula, "and that the matter of this parent nebula was in a finely divided solid or liquid state before aggregation. . . . It regards the knots of the nebula as the nuclei of the future planets and the nebulous haze as matter to be added to these nuclei to form the planets. It assumes that both the knots and the particles of the nebulous haze moved about the central mass in elliptical orbits of considerable but not excessive eccentricity. . . . It deduces a relatively slow growth of the earth, with a rising internal temperature developed in the central parts and creeping outward."

From the strictly geological standpoint the most important difference between the Nebular and the Planetesimal Hypotheses is that, according to the former, the earth has passed through a gaseous and a molten stage and therefore must have formed a crust by solidification, while the latter leads to the conclusion that the earth has been solid

from the beginning, and consequently never formed a crust of solidification.

"It is unfortunate," says W. B. Scott in his 'Introduction to Geology' (Macmillan Co.), "that an account of historical geology should begin with the most difficult and obscure part of the subject, but the treatment must be in accordance with the chronological order, and the oldest rocks are the least intelligible. The ordinary criteria of the historical method—namely, the stratigraphical succession and the comparison of fossils—fail us here almost entirely, and the only way of correlating the rocks of different regions and continents is by means of the characters of the rocks themselves. In the present state of knowledge 'lithological similarity' is not a safe guide. So many metamorphic rocks, once referred to the Archæan, have proved to be of much later date, that some cautious geologists, who have no confidence in 'lithological similarities,' prefer not to use the term Archæan at all, but to employ local terms for the oldest crystalline rocks exposed in a given district. The Archæan includes the most ancient rocks, often spoken of as the 'basement, or basal complex.' Its antiquity is best assured in regions where it is separated by thick series of sedimentary or metamorphic rocks from the Lower Cambrian, which can be certainly identified by its fossils."

The Archæan is composed of completely crystalline rocks of various types. Massive rocks, such as granite and basic eruptives, and foliated rocks, like gneissoid granite, gneiss, many varieties of schists, are intermingled in the most intricate way, a characteristic well expressed in the oft-used phrase of the basal or fundamental complex for the Archæan. The component mineral particles show plainly the intense dynamic metamorphism to which they have been subjected in their extremely complex arrangement and in their laminated and crushed condition. The rocks thus referred to the Archæan are not necessarily all of the same age, but they are all of vast antiquity and

older than any other known series. They are of very great but unknown thickness, for the bottom of them is nowhere to be seen, and even when thrown up into mountain ranges, erosion has in no case cut so deeply into these rocks as to expose anything different below them.

"The origin of the Archæan Rocks," Scott resumes, "is a problem which has given rise to a great deal of discussion, but a solution appears to be near. Independently, in many countries, observers have reached the conclusion that these rocks are divisible into two great series, a schist series composed chiefly of highly metamorphosed sedimentary and volcanic rocks, and a gneissoid granite series, which is intrusive and later than the former.

"Assuming that this conclusion is true, at least as a working hypothesis, it involves certain curious consequences. Surface lava flows and volcanic tuffs, and still more sedimentary rocks, necessarily imply a solid floor upon which they were laid down, but of this floor not a trace has anywhere been found. The question immediately arises, What has become of it? No answer to this question can yet be given, but apparently the most likely suggestion is that the ascending floods of molten magma, which gave rise to the gneissoid granites, must have melted and assimilated it. If this were only a local phenomenon, there would be nothing very surprising about it, but it would seem to be true of the entire globe, and this is a startling conclusion. It would appear, then, that a solid crust, however formed, was for a very long time sufficiently rigid and stable to allow a great thickness of sedimentary and volcanic rocks to be accumulated upon it and then was engulfed and destroyed by a universally ascending magma, tho it is not necessary to suppose that this took place simultaneously over the whole earth or even within a relatively short period of time; it may have required ages in the accomplishment. Furthermore, it must not be forgotten that remnants of the floor may yet be discovered in little-known regions. If this complete and universal assimilation actu-

ally took place, it is an absolutely unique phenomenon in the recorded history of the earth, tho something more or less similar may have happened many times before that record began."

The present writer is not entirely in agreement with Professor Scott as to the following division of geologic time, but in view of the fact that the sequence used in this summary is taken from his 'Introduction to Geology,' no change will be made in the order of presentation.

"The Algonkian is the name proposed by the United States Geological Survey for the great series of sedimentary and metamorphic rocks which lie between the basal Archæan complex and the oldest Paleozoic strata; it is but little used outside of this country and is not universally employed even here, but it is beginning to make its way in Europe and serves a useful, tho possibly a temporary, purpose. While it is possible, tho not very likely, that more advanced knowledge may make it possible to distribute these rocks partly into the Archæan and partly into the Paleozoic, yet for the present, at least, it is better to form a separate grand division for them.

"The Algonkian rocks, which are widely distributed in North America, form an immensely thick mass of strata and of metamorphic rocks which are believed to represent those strata in other regions. These metamorphic rocks were long generally referred to as the Huronian, which was regarded as the upper portion of the Archæan, but, so far as can be learned, they occupy the same stratigraphical position as certain little changed sediments, between the fundamental complex below and the Cambrian above. At the base of the magnificent section exposed in the Grand Cañon of the Colorado is a very thick mass of strata, separated by great unconformities from the Archæan gneiss below and from the overlying Cambrian. This mass is again subdivided by minor unconformities into three series. The lower series, at least 1,000 feet thick, and perhaps more, is made up of stratified quartzites and semi-crystal

line schists, cut by intrusive granite. Above this come nearly 7,000 feet of sandstones, with included lava sheets, and at the top more than 5,000 feet of shales and limestones, in which a few fossils have been found. The two upper series are not at all metamorphic. All these strata are steeply inclined and upon their truncated edges rests the sandstone referred by Mr. Walcott to the Middle Cambrian."

In the Grand Cañon and Montana determinable fossils have been found in the less changed sediments, but they are too few and scanty to indicate much of the life of the times. Evidences of life are not wanting in the metamorphic rocks of the eastern and northern regions, but they are indirect. The strata of crystallized limestone are indications of the presence of animal life in the Algonkian seas. The great quantities of graphite diffused through many of the schists and the beds of iron ore likewise tend to show the existence of plants at the same time. More conclusive are the determinable fossils obtained in the Belt series of Montana and in the Grand Cañon series, which include the tracks of worms, brachiopods and fragments of large Crustacea referable to the Eurypterida. Such remains imply a long antecedent history of life, the records of which remain to be discovered.

With regard to the comparative value of the pre-Cambrian rocks in the chronology of geological history no precise statement can be made, but various circumstances show that they must represent an enormous period of time. From the general character of the Cambrian fauna it must be regarded as certain that life had existed on the earth for a long series of ages before that fauna appeared, in order that such well-advanced grades of organization should then have been reached. One of the most interesting chapters of geological history would be supplied if some adequate account could be given of the stages of this long pre-Cambrian evolution.

"The Paleozoic is the oldest of the three main groups

into which the normal fossiliferous strata are divided," continues Scott. "It forms the first legible volume of the earth's history, and in interpreting it speculation and hypothesis play a much less prominent part than in the pre-Cambrian volume. The Paleozoic rocks are conglomerates, sandstones, shales and limestones, with quite extensive areas of metamorphic rocks, and associated igneous masses, both volcanic and plutonic. The thickness of these rocks is very great, estimated in Europe at a maximum of 100,000 feet. This does not imply that such a thickness is found in any one place, but that if the maximum thicknesses of each of the subordinate divisions be added together, they will amount to that sum.

"In this country more than 25,000 feet of Paleozoic strata are exposed in the much-folded and profoundly denuded Appalachian Mountains, but in the Mississippi valley they attain only a fraction of that thickness. These rocks are, in the vast majority of cases, of marine origin, but some fresh-water beds are known, and very extensive swamp and river deposits have preserved a record of much of the land life of the era, especially of its later portions. That there must have been land-surfaces is abundantly shown by the immense thickness and extent of the strata, all of which were derived from the waste of the land. Both in Europe and in North America the land areas were prevailing toward the north and are doubtless indicated, in part, by the great regions of the pre-Cambrian metamorphic rocks.

"The general character of the Paleozoic beds shows that they were, in large measure, laid down in shallow water in the neighborhood of land. Their great thickness indicates further the enormous denudation which the land areas underwent. The calculation has not been made for this country, but for Great Britain Geikie states that the lower half of the Paleozoic group represents the waste of a plateau larger than Spain and 5,000 feet high, cut down to base level. Very widespread disturbances of the earth's

crust before the beginning of the Paleozoic era and at its close have produced well-nigh universal uncomformities with both the underlying pre-Cambrian and the overlying Mesozoic rocks; at only a few points are transitional series found.

"Early in Paleozoic time were established the main geographical outlines which dominated the growth of the North American continent, a growth which was for the most part steady and tranquil. These conditions may be briefly stated as the formation of a great interior continental sea, divided from the Atlantic and the Pacific by more or less extensive and variable land areas. There are thus three principal regions of continental development: those of the Atlantic and Pacific borders and the interior. In addition, the eastern border is subdivided by pre-Cambrian ridges into subordinate areas of deposition. At the present time the surface rocks over the eastern half of the continent are prevailingly Paleozoic, extending chiefly southward and southeastward from the great pre-Cambrian mass of the north. Paleozoic time was of vast length, perhaps exceeding that of the combined Mesozoic and Cenozoic eras.

"The subdivisions of the Paleozoic are very clearly marked, locally often by unconformities, but on a wide scale by the changes in the character of the fossils.

"Paleozoic life possesses an individuality not less distinctly marked than that of the group of strata, which demarcates it very sharply from the life of succeeding periods and gives a certain unity of character to the successive assemblages of plants (floras) and of animals (faunas). The era is remarkable both for what it possesses and what it lacks. Among plants the vegetation is made up principally of Cryptogams, seaweeds, ferns, club-mosses and horsetails. Especially characteristic are the gigantic tree-like club-mosses and horsetails, which are now represented only by very small herbaceous forms. The only flowering plants known are the Gymnosperms, the Cycads and their

allies; no Angiosperms have been discovered. Paleozoic forests must have been singularly gloomy and monotonous, lacking entirely the bright flowers and changing foliage of later periods.

"The Paleozoic fauna is largely made up of marine invertebrates, in the earlier periods entirely so—*i.e.*, so far

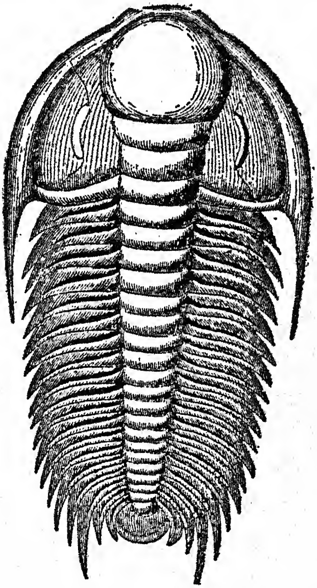


Fig. 34 —Trilobite; Cambrian Period.

as we have yet learned, tho land life surely began before the oldest records of it yet discovered. Graptolites and Hydroid Corals, true Corals, Echinoderms (especially Crinoids, Cystideans and Blastoids), long-hinged and hingeless Brachiopods, Mollusca (particularly the Nautiloid Cephalopods) and the crustacean groups of Trilo-

bites and Eurypterida are the most abundant and characteristic types of animal life. Insects, centipedes and spiders were common toward the end of the era. Cambrian rocks contain no fossil vertebrates, but they make their appearance in the Ordovician. For long ages the only vertebrates were fishes and certain low types allied to the fishes, but at the end of the Devonian and in the Carboniferous appeared the Amphibia, followed in the Permian by true Reptiles. Teleosts, such as make up by far the largest part of the modern fish-fauna, both marine and fresh-water, as well as birds and mammals, are entirely absent from the Paleozoic.

"The overwhelming majority of Paleozoic species, and even genera, fail to pass over into the Mesozoic, and even in the larger groups which continued to flourish almost always a more or less complete change of structure occurs, so that Paleozoic corals, Echinoderms and fishes, for example, are very markedly distinct from those which succeeded them. The difference is generally in the direction of greater primitiveness of structure in the older forms, Paleozoic types standing in somewhat the same relation to subsequent types as the embryo does to the adult.

"In the vast periods of time included in the Paleozoic era occurred some remarkable climatic vicissitudes. Times of widespread glaciation occurred in the Lower Cambrian of Norway and China, probably of Australia and perhaps also of South Africa, in the Devonian of South Africa and in the Permian of the latter region, India, Australia and South America, perhaps also in Europe and North America. For most of the era, however, the climate appears to have been mild and equable on the whole, very much the same kinds of animals and plants occurring in high as in low latitudes. In short, we can detect no evidence of climatic zones as being distinctly marked in those periods."

So far as they are accessible to observation, the Cambrian rocks are chiefly such as are laid down in shallow water near shore, conglomerates, sandstones and shales,

which are ripple-marked in a way that betrays their shoal-water origin. During Cambrian times the sea was slowly advancing over the land in North America, and the geography of the continent was very different at the close of the period from what it had been at the beginning. In the Lower Cambrian the land areas are inferred to have been somewhat as follows: First there was the great northern mass of crystalline Archæan and Algonkian rocks, but this was probably much more extensive than the present exposures of pre-Cambrian rocks would indicate. It probably covered the whole Mississippi valley down to 30° N. lat. and extended westward beyond the Rocky Mountains. Long, narrow strips of land, alternating with narrow sounds, occupied part of New England and the maritime provinces of Canada, while an Appalachian land, whose western line is marked by the present Blue Ridge, extended eastward an unknown distance into the Atlantic. On the western shore of the Appalachian land was a narrow arm of the sea, which opened south and nearly separated this land area from the great mass of the continent. The site of the Sierra Nevada was occupied by a long, narrow land, running from Puget Sound to Mexico, and another such area was found in eastern British Columbia. The Great Basin region was under water. Around these shores were laid down the coarser deposits of the Lower Cambrian, with great masses of shales and thick limestones in deeper water.

Much interest necessarily attaches to Cambrian fossils, for excepting the few and obscure organic remains obtained from pre-Cambrian strata, they are the oldest assemblage of organisms yet known. They form no doubt only a meager representation of the fauna of which they were once a living part. One of the first reflections which they suggest is that they present far too varied and highly organized a suite of organisms to allow us for a moment to suppose that they indicate the first fauna of our earth's surface. Unquestionably they must have had a long series

of ancestors, tho of these still earlier forms such slight traces have yet been recovered. Thus, at the very outset of his study of stratigraphical geology, the observer is confronted with a proof of the imperfection of the geological record. When he begins the examination of the Cambrian fauna, so far as it has been preserved, he at once encounters further evidence of imperfection. Whole tribes of animals, which almost certainly were represented in Cambrian seas, have entirely disappeared, while those of which remains have been preserved belong to different and widely separated divisions of invertebrate life.

Of the plants of the Cambrian strata nothing is surely known. Certain marks on the bedding-planes of strata have been regarded as seaweeds, but they are too obscure for determination and many are worm tracks.

The fauna is principally made up of Trilobites and Brachiopods, but many other types are represented also. Trilobites have a more or less distinctly three-lobed body, at one end of which is the head-shield, usually with a pair of fixed compound eyes; at the other end is the tail-shield, and between the two shields is a ringed or jointed body made up of a variable number of movable segments. The Trilobites display an extraordinary variety in form and size, in the proportions of the head and tail shields, in the number of free segments and in the development of spines. Brachiopods are among the most abundant of Cambrian fossils. Most of them belong to the lower order of the class, 'Inarticulata,' in which the shells are mostly horny and the two valves are not articulated together by a hinge. The horny-shelled types, 'Linnarssonia,' 'Lingulepis' and 'Lingulella,' are of great interest, as they differ but little from certain brachiopods which still exist. The second order of Brachiopods, the 'Articulata,' which have calcareous shells connected by an elaborate hinge, were more common in the Upper Cambrian.

"Sir Roderick Murchison divided his great Silurian system primarily into two parts, Upper and Lower. This

method of classification is generally followed even at the present day, altho it is widely recognised that the most decided break in the entire Paleozoic group is the one between these divisions. In 1879 Professor Lapworth proposed to give due emphasis to this distinction by erecting the Lower Silurian into a separate system, the 'Ordovician.' The name is taken from the 'Ordovici,' an ancient British tribe which dwelt in Wales during Roman times. Lapworth's example is now largely followed in England and the United States, but on the continent of Europe the name 'Silurian' is still retained for both systems.

"The passage from Cambrian to Ordovician was gradual, without any marked physical break. Only where the Upper Cambrian is sandy, as in New York, is there a decided change in the character of sedimentation. In the latter part of the Cambrian a great inland sea had been established over what is now the Mississippi valley and, with frequent fluctuations in depth and modifications in form, it was to persist for long periods as one of the salient features of Paleozoic geography. This sea was separated from the Atlantic by the land mass called Appalachia, and on the western side it was demarcated from the Pacific by islands of undetermined size.

"At the end of the period came a time of widespread disturbance, upheaval and mountain-making, the traces of which are still plain in North America and Europe, especially along the Atlantic slope of each continent. The Interior Sea appears to have been entirely drained; at all events no deposits transitional to the Silurian are known from that region. In the West and Northwest large areas remained land for long periods, but the Interior Sea was soon reëstablished in the Mississippi valley. Some narrow strips of land were added to the margin of the Cambrian coasts, and on a line running through southern Ohio, Kentucky and Tennessee a low, broad arch, the formation of which appears to have begun early in the Ordovician, was

forced up by lateral compression. This is called the 'Cincinnati anticline or axis.'

"Ordovician life displays a notable advance over that of the Cambrian, becoming not only very much more varied and luxuriant, but also of a distinctly higher grade. During the long ages of the period also very decided progress was made, and when the Ordovician came to its close all of the great types of marine invertebrates and most of their more important subdivisions had come into existence. In a general way the life of the Ordovician is an expansion of that of the Cambrian, tho but little direct connection between the two can yet be traced, and evidently there were great migrations of marine animals from some region which cannot yet be identified. Several groups of invertebrates attained their culmination and began to decline in the Ordovician, becoming much less important in subsequent periods. Thus the Graptolites, the Cystoidean order of Echinoderms, the straight-shelled Cephalopods (orthoceratites) among Mollusks, and the Trilobites were never so abundant and so varied as during this period.

"In America no plants above the grade of seaweeds and coralline Algæ have been discovered, but in Europe a few of the higher Cryptogams are doubtfully reported. The flora of the Devonian, however, renders it highly probable that land plants were already well advanced in the Ordovician, and their remains may be discovered at any time. This must remain a matter of accident, for the known Ordovician rocks are almost all marine, which is not a favorable circumstance for the preservation of land plants. Such discoveries have, indeed, already been reported, but the evidence for them is not satisfactory.

"The general disturbance which closed the Ordovician period appears to have greatly increased the extent of the continent. An important feature in the Silurian geography of eastern North America was the establishment of the 'Cumberland Basin,' or 'Appalachian Mediterranean' as it has been called. This large sea lay to the eastward of the

Interior Sea, from which it would seem to have been either completely separated or so nearly so that the species of marine animals inhabiting the two bodies of water were very different. The Cumberland Basin was east of the Catskill-Helderberg line in New York and its western shore crossed New Jersey and curved westward beyond the center of Pennsylvania, whence it ran southwest more or less parallel with the Appalachian line, toward which it

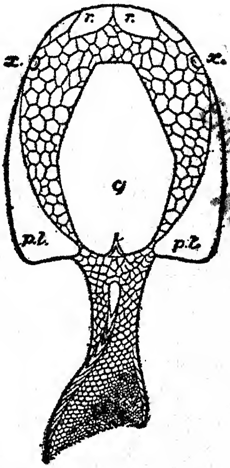


Fig. 35 —PRIMITIVE OSTRACODERM; SILURIAN PERIOD. (Scott.)

curved eastward in southern West Virginia. The Interior Sea underwent a succession of oscillations much like those which had affected it during the Ordovician; it was apparently closed at the south, but extended northwestward to the Arctic Sea, while its east-west diameter had been greatly reduced from that of the Ordovician.

Silurian life is the continuation and advance of the same organic system as flourished in the Ordovician, certain

groups diminishing, others expanding; and some new groups now make their first appearance.

In parts of North America the Silurian passed so gradually and gently into the Devonian that it is difficult to draw the line between the two systems. Some disturbances, however, took place in Ireland, Wales and the north of England, for in these localities the Devonian lies unconformably upon the Silurian. In other parts of Europe the transition was gradual.

"Comparing the rocks of the Ordovician, Silurian and Devonian as these are developed in the Appalachian and adjoining regions, a certain rhythmic or periodic recurrence of events may be discovered among them. Each system is characterized by a great and very widespread limestone formation, and in each the limestone is succeeded by shales or other clastic rocks, due to an increase of terrigenous material, and each was closed by a more or less widespread emergence of the sea-bottom. Each began with a subsidence which gradually extended to a maximum at the time when the great limestone was formed. The parallelisms are not exact, but they are certainly suggestive.

"The European Devonian appears in three different facies; one of these is the 'Old Red Sandstone,' which is largely of continental origin and lies to the north. The second facies is of marine, shoal-water deposits and runs from Devonshire, through Belgium, the northern part of the lower Rhenish and the Hartz Mountains to Poland; and the third, extending from northwestern France, through Germany to Bohemia, was laid down in deeper water.

"The period began in Europe with an advance of the sea over the land in many places, reaching its maximum extension in the latter part of the period, but beginning to retire before the opening of the Carboniferous. This subsidence removed the barrier which in Ordovician and Silurian times had separated the northern and southern seas, but was accompanied by the formation of closed basins farther

to the north. Europe then was largely an open sea with many islands, and where the waters were sufficiently clear and free from terrigenous sediment coral reefs were extensively formed.

"The 'Old Red Sandstone' is of particular interest, because owing to the peculiar circumstances of its formation it has preserved a record of Devonian land life, which, tho fragmentary, is far more complete than anything we possess from the more ancient periods. These strata were laid down in closed basins (sometimes, perhaps, in fresh-water lakes), which had only a restricted communication with the sea, and it may be that these accumulations were

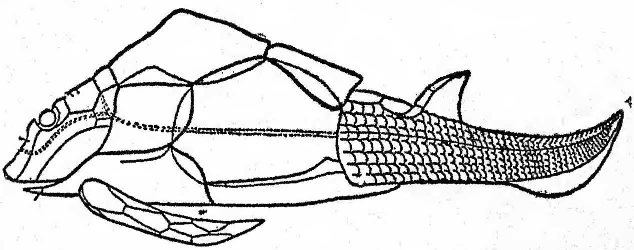


Fig. 36 —Later Ostracoderm, 'Pterichthys'; Devonian Period. (Scott.)

partly made by the wind, tho there is no gypsum or salt in the beds to indicate the prevalence of desert conditions.

"The life of the Devonian is, in its larger outlines, very like that of the Silurian, but with many significant differences, which are due, on the one hand, to the dying out of several of the older groups of animals, and on the other, to the great expansion of forms which in the Silurian had played but a subordinate rôle.

"The fossils show that in Devonian times the land was already clothed with a varied, rich and luxuriant vegetation of the same general type as that whose scanty traces are found in Silurian strata. All the higher Cryptogams

are represented, and by large tree-like forms as well as by small herbaceous plants."

The Carboniferous system of rocks has received its name from the seams of coal which form one of its distinguishing characters in many parts of the world. Both in Europe and America it may be seen passing down conformably into the Devonian and Old Red Sandstone. So insensible indeed is the gradation in many consecutive sections where the two systems join each other that no sharp line can there be drawn between them. This stratigraphical passage is likewise frequently associated with a corresponding commingling of organic remains, either by the ascent of undoubted Devonian species into the lower parts of the Carboniferous series or by the appearance in the Upper Devonian beds of species which attained their maximum development in Carboniferous times. Hence there can be no doubt as to the true place of the Carboniferous system in the geological record.

In some places, however, the higher members of this system are found resting unconformably upon Devonian or older rocks, so that local disturbances of considerable magnitude occurred before or during the Carboniferous period. In Russia, and still more in China and western North America, Carboniferous rocks cover thousands of square miles in horizontal or only very gently undulating sheets.

The Carboniferous is divisible into two sharply marked portions, the Lower, or Mississippian, and Upper, or Pennsylvanian, a distinction which is applicable in all the continents in which the strata of this period have been carefully studied.

During this period the Interior Sea expanded widely, probably covering nearly the whole of the Great Plains, and most of the old land areas of the West and Southwest, which had persisted through more or less of the Silurian and Devonian, were extensively submerged, probably including all of Mexico and the northern part of Central America. West of the Rocky Mountains the Carboniferous

is much the most widely extended of any of the Paleozoic systems, the sea reaching through British Columbia on both sides of the Gold Range into southeastern Alaska.

The remarkable profusion of the vegetation of the Carboniferous period, not only in the Old World but in the New, suggested the idea that the atmosphere was then much more charged with carbonic acid than it now is. Undoubtedly there has been a continual abstraction of this gas from the atmosphere ever since land-plants began to live on the earth's surface, and it is allowable to infer that the proportion of it in the air in Paleozoic time may have been somewhat greater than now. But the difference could hardly have been serious, otherwise it seems incredible that the numerous insects, labyrinthodonts and other air-breathers could have existed. Most probably the luxuriance of the flora is rather to be ascribed to the warm moist climate which in Carboniferous times appears to have spread over the globe even into Arctic latitudes. On the other hand, evidence has been adduced to support the view that in spite of the genial temperature indicated by the vegetation there were glaciers even in tropical and subtropical regions.

The life of this period is thoroly Paleozoic and continues along the lines already marked out in the Devonian, but there are some notable changes and advances which look toward the Mesozoic order of things.

"The Carboniferous vegetation," Scott points out, "is of very much the same character as that of the Devonian, but owing to the peculiar physical geography of the times the plants were preserved as fossils in a much more complete state and in vastly larger numbers. The flora is composed entirely of the higher Cryptogams and the Gymnosperms, no plant with conspicuous flowers having come into existence, so far as we yet know. By far the most abundant of Carboniferous plants are the 'Ferns,' Filicales, which flourished in multitudes of species and individuals, both as tall trees and as lowly herbaceous plants.

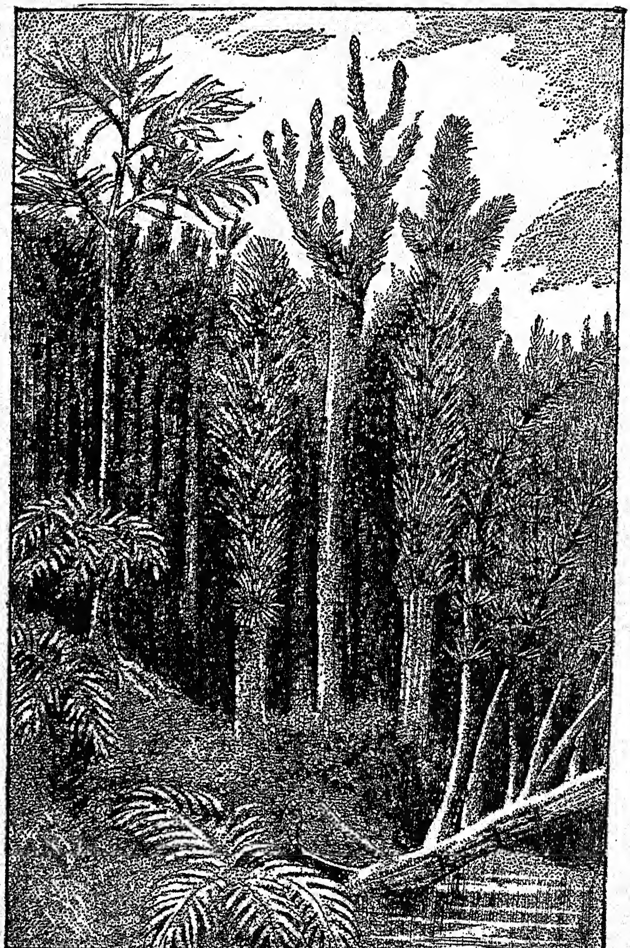


Fig. 37 —Vegetation of Carboniferous Period.

Many of these ferns cannot yet be compared with modern ones, because the organs necessary for trustworthy classification have not been recovered, and such are named in accordance with the venation of the leaves. In other cases the comparison with existing ferns may be definitely made, and these remains show that many of the modern families had representatives in the Carboniferous forests and swamps."

In North America the Permian followed upon the Carboniferous with hardly a break, so that the distinction between the two systems must be made entirely upon the fossils, which change very gradually, by drawing a somewhat arbitrary line of demarcation. In various countries there is no general agreement regarding the upper boundary of the Carboniferous. The Lower Permian of Europe is remarkable for the great masses of volcanic rocks, lava flows and tuffs which it contains and which occur in Great Britain, France, Germany and the Alps. This is in strong contrast to the corresponding American series, which gives no evidence of vulcanism.

The animals and plants of the Permian are transitional between those of the Paleozoic and those of the Mesozoic eras. Here are found the last of many types which had persisted ever since Cambrian times, associated with forms which represent the incipient stages of characteristic Mesozoic types, together with others peculiar to the Permian. The flora of the Lower Permian is decidedly Paleozoic in character and that of the Upper Permian as decidedly Mesozoic, so that if the line dividing these two great eras were drawn in accordance with the vegetation, it would pass through the Permian. Even in the Lower Permian, however, the change from the Carboniferous flora is a marked one, a change which may be largely explained by the increasing aridity of the climate.

The Mesozoic formations have been grouped in three great divisions, which, tho first defined in Europe, are found to have their representative series of rocks and fos-

sils all over the world. The oldest of these is the Trias or Triassic system, followed by the Jurassic and Cretaceous. "The life of the Mesozoic," Scott continues again, "constitutes a very distinctly marked assemblage of types, differing both from their predecessors of the Paleozoic and their successors of the Cenozoic. In the course of the era the Plants and marine Invertebrates attained substantially their modern condition, tho the Vertebrates remain throughout the era very different from later ones. Even in the Vertebrates, however, the beginnings of the newer order of things may be traced. In the earlier two periods, the Triassic and Jurassic, vegetation is almost confined to the groups of 'Ferns,' 'Cycads' and 'Conifers,' but with the Cretaceous come in the 'Angiosperms,' both 'Monocotyledons' and 'Dicotyledons,' and since then the changes have been merely in matters of detail.

"Among the 'Crustacea,' the 'Trilobites' and 'Eurypterids' went out, but all the modern groups were well represented, tho many of the Mesozoic genera are no longer to be found in the seas of to-day. Insects reached nearly their modern condition so far as the large groups are concerned, butterflies, bees, wasps, ants, flies, beetles, etc., being added to the older orthopters and neuropters.

"Fishes became modernized before the close of the era, the Bony Fishes having acquired their present predominance. The Amphibia took a subordinate place, and after flourishing for a time, the great Stegocephalia died out, leaving only the pigmy salamanders and frogs of the present. Birds and Mammals made their first appearance, the former advancing rapidly to nearly their present grade of organization, tho not reaching their present diversity, while the mammals remained throughout the era very small, primitive and inconspicuous. The most significant and characteristic feature of Mesozoic life is the dominance of the Reptiles, which, in size, in numbers and in diversified adaptation to various conditions of life, attained an extraordinary height of development. The

Mesozoic is called the 'Era of Reptiles,' because these were the dominant forms of life. They filled all the rôles now taken by birds and mammals; they covered the land with gigantic herbivorous and carnivorous forms, they swarmed in the sea, and, as literal flying dragons, they dominated the air. At the present time there are only five orders of reptiles in existence, and of these only the crocodiles and a few snakes attain really large size. In the Mesozoic era no less than twenty-five reptilian orders flourished, and many of them had gigantic members. Some were the largest land animals that ever existed, and the sea dragons rivaled the whales in size. Nothing so clearly shows that the Mesozoic era is a great historical fact as the dominance of its reptiles.

"The Triassic Period is so named from the very conspicuous threefold subdivision of this system of strata in Germany, where its rocks were first studied in detail and where they occupy a greater area than in any other European country. The German Trias is, however, not the usual facies of the system, but a very peculiar one, and cannot be taken as the standard of comparison for most other countries. In the early part, at least, of the period both North and South America extended farther east than at present, and no marine Triassic rocks are known on the Atlantic slope of either continent, but they are extensively displayed on the Pacific side. The land barrier which during the Paleozoic era had bounded the Great Basin sea on the west was submerged and the Pacific extended over the site of the Sierras, covering western Nevada and sending a gulf into southeastern Idaho, and in British Columbia it transgressed eastward across the present mountains and it covered part of the coast of Alaska.

"On the Atlantic side of North America the course of events was entirely different. In the latter half of the period was formed a series of long, narrow troughs, running closely parallel to the trend of the Appalachian Mountains, but separated from them by the ridges of

metamorphic and crystalline rocks which follow those mountains on the east, and which then probably had a considerable altitude, much greater than at present. In those troughs was laid down the enormous thickness of non-marine rocks which constitute the Newark series and are now found in several disconnected areas from Nova Scotia to North Carolina.

"Triassic life is entirely different from anything that had preceded it, tho the way for the change was already preparing in the Permian. The Upper Permian, if classified by its plants alone, would be referred to the Mesozoic rather than to the Paleozoic; therefore it is not surprising that the Triassic flora is very similar to that of the Upper Permian, tho the Upper Trias marks a decided advance among the plants. Among the animals a considerable number of surviving Paleozoic types persist into the Trias which do not pass into the Jurassic."

William Smith, the father of Historical Geology, was the first to work out the divisions of the Jurassic, which he did early in the last century. Smith's name for the system, "Oölitic," has been abandoned in favor of the term Jurassic, which was first used by Brongniart and Humboldt. It was taken from the Jura Mountains of Switzerland, where the rocks of this system are admirably displayed. In Europe the Jurassic has long been a favorite subject of study, because of the marvelous wealth of beautifully preserved fossils which it contains. For this reason the Jurassic is known with a fulness of detail such as has been acquired regarding very few of the other systems; and no less than thirty well-defined subdivisions have been traced through many countries of the Old World. In this country the Jurassic is ill represented and its divisions are not clear.

"The life of the Jurassic has been preserved in wonderful fulness and variety; but with comparatively few exceptions our knowledge of it has been principally derived from Europe, where a host of eminent geologists have

Fig. 38 —ARCHÆOPTERYX, JURASSIC PERIOD. (Parker & Haswell.)

long studied the great wealth of material. The contrast between North America and Europe in regard to the relative abundance of Jurassic marine fossils is seen from the fact that while in Great Britain alone more than 4,000 species have been described, in America hardly one-tenth of that number has so far been found. The flora of the Jurassic differs little, on the whole, from that of the Trias, and is made up of Ferns, Horsetails, Cycads, Conifers and Gingkos.

"The name 'Cretaceous' is derived from the Latin word for chalk, 'Creta,' because in England, where the name was early used, the thick masses of chalk are the most conspicuous members of the system. Tho first made known in England, the main subdivisions of the Cretaceous, as employed in geological literature, bear French names, which have proved themselves better adapted to general use.

"In very marked contrast to the scanty development of the Jura, the Cretaceous strata of North America are displayed on a vast scale and cover enormous areas of the continent, eloquent witnesses of the great geographical changes in that long period. Continental, estuarine and marine rocks are all well represented, and, in consequence, our information regarding the life of North America and its seas during Cretaceous times is incomparably more complete than it is for the Triassic and Jurassic.

"It was during the Upper Cretaceous that the great subsidence took place which affected nearly all parts of the continent and brought the sea in over vast areas where for ages had been dry land. South of New England the Atlantic coastal plain was submerged, and in New Jersey, at least, the waters covered even the nearly base-leveled Triassic belt, bringing the sea up to the foot of the crystalline highlands. The lowlands of Maryland, Virginia and the Carolinas and all of Florida were under the ocean, and the Gulf of Mexico was extended northward in a great bay (the Mississippi embayment), covering western

Tennessee and Kentucky and extending into southern Illinois.

"In the southern region the Lower Cretaceous was terminated by an upheaval, which caused the Comanchean Sea to withdraw from Texas and the area to the west and north of it. This mid-Cretaceous land epoch must have continued for a considerable time, permitting extensive denudation and a complete change in the fauna. Wherever the marine Upper Cretaceous is in contact with the Comanche limestones north of Mexico the two are unconformable, and no species of animal is known to pass from one to the other. In Mexico the Lower Cretaceous passes into the Upper without a break, the disturbances there taking place at a later date.

"The Mesozoic era was closed in the West, as the Paleozoic had been in the East, by a time of great mountain making, and to this movement is attributed the formation of most of the great Western mountain chains. From the Arctic Ocean to Mexico the effects of the disturbance were apparent. The Rocky Mountains, the Wasatch and Uinta ranges, the high plateaus of Utah and Arizona and the mountains of western Texas date from this time, tho subsequent movements have greatly modified them. Vast volcanic outbreaks accompanied the upheaval, which was on a far grander scale than the Appalachian revolution had been.

"The life of the Cretaceous displays so great an advance over that of the Jurassic that the change may fairly be called a revolution. In the latter part of the Lower and in all the Upper Cretaceous of North America the flora assumes an almost completely modern character, and nearly all of our common kinds of forest trees are represented: Sassafras, Poplars, Willows, Oaks, Maples, Elms, Beeches, Chestnuts and very many others. A new element is the Monocotyledonous group of Palms, which speedily assumes great importance. Cretaceous animals are sufficiently different from those of the Jurassic, but the

change is not so revolutionary as has been found among the plants.

"The life of the Cenozoic era is very clearly demarcated from that of the Mesozoic, tho many modern char-

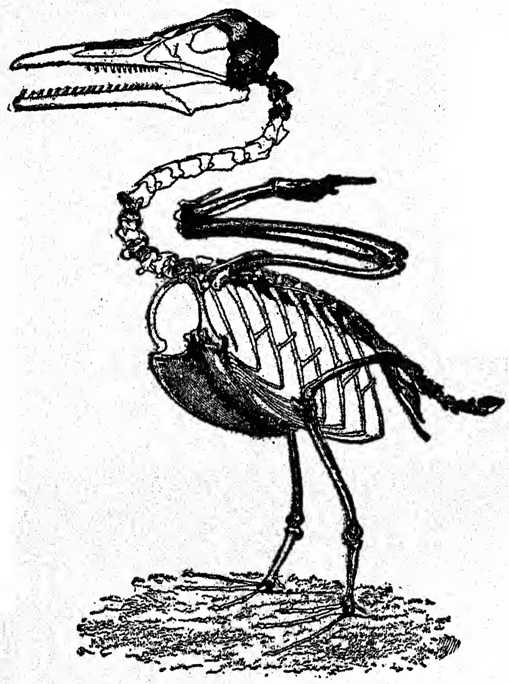


Fig. 39 —ICHTHYORNIS, CRETACEOUS PERIOD. (Marsh.)

acteristics began in the Cretaceous or even earlier. The plants and invertebrate animals nearly all belong to genera which are still living, and the proportion of modern species steadily increases as we approximate the present time. The Fishes, Amphibia and Reptiles differ but little from

those of modern times, and the Birds take on the diversity and relative importance which characterize them now. Above all, the Mammals undergo a wonderful expansion and take the place of the vanished reptiles, giving to Cenozoic time an altogether different character from all that went before it. The great geographical and climatic changes produced migrations of land animals and plants upon a grand scale, from continent to continent and from zone to zone, the result of which is the distribution of living beings over the earth's surface as we find it to-day."

The Tertiary Period witnessed the development of the present distribution of land and sea and the final upheaval of most of the great mountain-chains of the globe. Some of the most colossal disturbances of the terrestrial crust of which any record remains took place during these periods. Not only was the floor of the Cretaceous sea upraised into low lands, with lagoons, estuaries and lakes, but afterward, throughout the heart of the Old World, from the Pyrenees to Japan, the bed of the early Tertiary or nummulitic sea was upheaved into a succession of giant mountains, some portions of that sea-floor now standing at a height of at least 16,500 feet above the sea.

During Tertiary time there was an abundant manifestation of volcanic activity. After a long quiescence during the succession of Mesozoic periods volcanoes broke forth with great vigor both in the Old and the New World. Vast floods of lava were poured out and a copious variety of rocks was produced, ranging from highly basic basalts, limburgites and peridotites to rhyolites, quartz-felsites and granites.

The name Tertiary was given by Cuvier and Brongniart early in the last century to the succession of marine, brackish-water and fresh-water beds in the Paris basin. Sir Charles Lyell many years later proposed the division of the Tertiary into three parts, Eocene (from the Greek eos, the dawn, and kainos, recent), Miocene (meion, less, and kainos) and Pliocene (pleion, more, and kainos), a

scheme which is still used, modified by Beyrich through the insertion of a fourth epoch, the Oligocene (oligos, little or in small degree, and kainos). Last of all, the Lower Eocene has been separated under the name Paleocene (palaios, ancient, as in Paleozoic), a change proposed thirty years ago by the botanist Schimper, but only lately coming into wider favor. It has become customary to distinguish between the older and newer parts of the Tertiary by grouping together the Eocene and Oligocene into the Paleogene and the Miocene and Pliocene into the Neogene.

The Post-Tertiary or Quaternary portion of the Geological Record includes the various superficial deposits in which nearly all the mollusca are of still living species. It is usually subdivided into two series: (1) An older group of deposits in which many of the mammals are of extinct species (to this group the names Pleistocene, Post-Pliocene and Diluvial have been given) and (2) a later series, wherein the mammals are all, or nearly all, of still living species, to which the names Recent, Alluvial and Human have been assigned. These subdivisions, however, are confessedly very artificial, and it is often exceedingly difficult to draw any line between them. The gradual refrigeration of climate at the close of the Tertiary ages affected the higher latitudes alike of the Old and the New World.

"As the cold increased," says Geikie, "the whole of the north of Europe came eventually to be buried under ice, which, filling up the basins of the Baltic and North Sea, spread over the plains even as far south as close to the site of London and in Silesia and Gallicia to the 50th parallel of latitude. Beyond the limits reached by the northern ice-sheet the climate was so arctic that snow-fields and glaciers stretched even over the comparatively low hills of the Lyonnais and Beaujolais in the heart of France. The Alps were loaded with vast snow-fields, from which enormous glaciers descended into the plains on

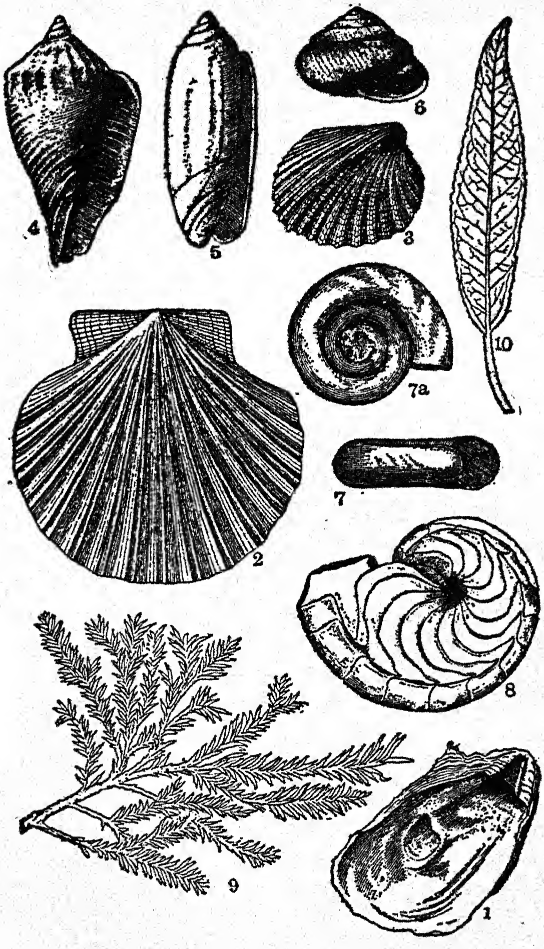


Fig. 40 —American Tertiary Fossils.

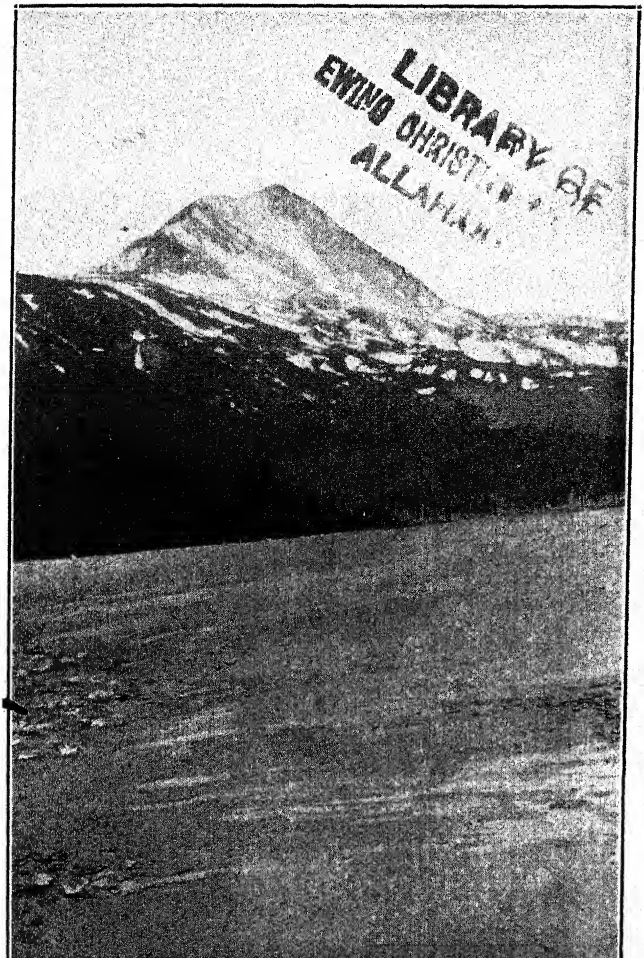
Nos. 1, 2, 5, 6 and 10, Miocene; Nos. 3, 4, 8 and 9, Eocene; No. 7, doubtful. (Scott)

either side, overriding ranges of minor hills on their way. The Pyrenees were in like manner covered, while snow-fields and glaciers extended southward for some distance over the Iberian peninsula. In North America also, Canada and the Eastern States of the American Union, down to about the 40th parallel of north latitude, lay under the northern ice-sheet.

"Owing mainly to the direction of the prevalent moisture-bearing winds, the snowfall was greatest toward the west and northwest, and in the direction of Scandinavia the ice-sheets attained their greatest thickness. The Scandinavian ice joined that which spread over Britain, where the dimensions of the sheet were likewise great. Many mountains in the Scottish Highlands show marks of the ice-sheet at heights of 3,000 feet and more. If to this depth be added that of the deep lakes and fjords which were filled with ice, it is evident that the sheet may have been as much as 4,000 or 5,000 feet thick in the northern parts of Britain.

"This vast icy covering, like the Arctic and Antarctic ice-sheets of the present day, was in continual motion, slowly draining downward to lower levels. Toward the west its edge reached the sea, as in Greenland now, and must have advanced some distance along the sea-floor until it broke off into bergs that floated away northward. Toward the south and east it ended off upon land and no doubt discharged copious streams of glacier-water over the ground in its front. In northern Germany, Denmark, Finland and Scandinavia, the southern limits at which the ice rested a long while before retiring are indicated by long winding ramparts of detritus (Endmoräne). In North America also the southern edge of the ice-sheet is marked by similar 'terminal moraines,' which are well displayed from Pennsylvania to Dakota.

"When this glaciation took place the terrestrial surface of the northern hemisphere had acquired the main configuration which it presents to-day. The same ranges of



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MT. McKINLEY, 20,300 FEET, IN THE ALASKA RANGE, THE HIGHEST MOUNTAIN IN THE UNITED STATES.

hills and lines of valley which now serve to carry off the rainfall served then to direct the results of the snowfall seaward. The snow-sheds of the Ice Age probably corresponded essentially with the water-sheds of the present day. Yet there is evidence that the coincidence between them was not always exact. In some cases the snow and ice accumulated to so much greater a depth on one side of a ridge than on the other that the flow actually passed across the ridge, and detritus was carried out of one basin into another. A remarkable instance of this kind has been observed in the north of Scotland, where so thick was the ice-sheet that fragments of rock from the center of Sutherland have been carried up westward across the main water-parting of the country and have been dropped on the western side.

"In North America also abundant evidence is afforded of a northern ice-sheet which overrode Canada and the Eastern States, southward to about the 40th parallel of latitude in the valley of the Missouri. Several centers of dispersion have been noted from which this ice moved outward, chiefly in a general southerly direction, but in the middle part the ice streamed northward into the Arctic Ocean. The great mountain ranges farther south likewise nourished numerous valley glaciers, which radiated outward from the high ground.

"As great oscillations of climate took place during the Ice Age and in some cases probably lasted for a long time, the plants and animals both of land and sea could hardly fail to be seriously affected. During the cold intervals northern forms would probably migrate southward and in the warmer episodes southern forms would push their way northward. The Arctic terrestrial animals include the mammoth woolly rhinoceros, musk-sheep, reindeer, Arctic fox and lemming. The marine invertebrate fauna shared, tho in a less degree, in the effects of the meteorological and geographical changes. During the times of great cold

northern species found their way southward, some of them even as far as the basin of the Mediterranean."

The cause of the remarkable change of climate during late Tertiary and post-Tertiary time has given rise to much discussion, but is still without a completely satisfactory explanation. Some writers have favored the view that there has been a change in the position of the earth's axis or of its center of gravity. Others have suggested that the earth may have passed through hot and cold regions of space. Others, again, and notably Lyell, have called in the effects of stupendous terrestrial changes in the distribution of land and sea, on the assumption that elevation of land about the poles must cool the temperature of the globe, while elevation round the equator would raise it. But the amount of geographical transformation thus involved was so great and the evidence for it appeared to be so slender that geologists generally have been reluctant to accept this explanation. In the difficulty of accounting for the phenomena by any feasible operation on the earth itself, they by degrees accustomed themselves to the belief that the cold of the Glacial Period was not due to mere terrestrial changes, but was to be explained somehow as the result of cosmical causes.

Among the recent attempts to deal with the problem of the Ice Age is the hypothesis proposed by Professor Chamberlin on the basis of variations in the amount of carbon dioxide in the air. It is founded on the capacity of that gas for absorbing heat and to the effect that might be produced on the temperature of the air by even a comparatively small increase or diminution in the proportion of the gas. The suggestion is that while there is a general tendency to the diminution of that proportion there arise from time to time conditions, such as great volcanic discharges, whereby much carbonic dioxide is supplied to the atmosphere. On this view the Glacial Period would mark a time of great depletion of the gas, while the Arctic Miocene flora would indicate a time of comparative en-

richment. Other geologists have turned back to the idea of geographical changes. That considerable oscillations of the relative levels of land and sea took place during the Ice Age has been clearly determined. The general result of investigation favors the opinion that the land in the early part of that period stood much higher than now over the northern regions of Europe and North America. If one accepts the conclusions drawn from the prolongation of land-valleys upon the sea-floor to a depth of many hundred feet and from the distribution of dead littoral and shallow-water shells down to depths of 6,000 or 8,000 feet in the North Atlantic, it can be seen that a vast area of high land would, under these conditions, have existed. This higher elevation would undoubtedly tend to lower the temperature. Some of the upraised parts of the sea-floor might deflect warm ocean currents and thus still further increase the cold in the higher latitudes. But no satisfactory attempt has yet been made to trace out these changes geographically on actual evidence of their having occurred and to connect them with the phenomena of the Pleistocene Period.

The long succession of Pleistocene ages shaded without abrupt change of any kind into what is termed the Human or Recent Period. The Ice Age, or Glacial Period, may indeed be said still to exist in Europe. The snow-fields and glaciers have disappeared from Britain, France, the Vosges and the Harz, but they still linger among the Pyrenees, remain in larger mass among the Alps and spread over wide areas of northern Scandinavia. This dovetailing or overlapping of geological periods has been the rule from the beginning of time, the apparently abrupt transitions in the geological record being due to imperfections in the chronicle.

"The Human Period," resumes Geikie, "is above all distinguished by the presence and influence of man. It is difficult to determine how far back the limit of the period should be placed. The question has often been asked

whether man was coeval with the Ice Age. To give an answer, we must know within what limits the term Ice Age is used and to what particular country or district the question refers. For it is evident that even to-day man is contemporary with the Ice Age in the Alpine valleys and in Finland. There can be no doubt that he inhabited Europe after the greatest extension of the ice. He not improbably migrated with the animals that came from warmer climates into this continent during interglacial conditions. But that he remained when the climate again became cold enough to freeze the rivers and permit an Arctic fauna to roam far south into Europe is proved by the abundance of his flint implements in the thick river-gravels, into which they no doubt often fell through holes in the ice as he was fishing.

"The proofs of the existence of man in former geological periods are not to be expected solely or mainly in the occurrence of his own bodily remains as in the case of other animals. His bones are indeed now and then to be found, but in the vast majority of cases his former presence is revealed by the implements he has left behind him, formed of stone, metal or bone. The history of the Bronze and Iron Ages in Europe is told in great fulness, but belongs more fittingly to the domain of the archeologist, who claims as his proper field of research the history of man upon the globe. The remains from which the record of these ages is compiled are objects of human manufacture, graves, cairns, sculptured stones, etc., and their relative dates have in most cases to be decided, not upon geological but upon archeological grounds. When, however, the sequence of human relics can be shown by the order in which they have been successively entombed, the inquiry is strictly geological and the reasoning is as logical and trustworthy as in the case of any other kind of fossils."

The Age of the Earth is another matter which geologists must needs speak of in terms of extreme guardedness.

Reasoning by analogy, it is true, there is a certain standard to be secured. Thus, for example, when it is discovered that water flowing at a certain speed cuts away the particles of a certain rock so many fractions of an inch in a decade, it is assumed that where so many feet have been cut away from a certain rock by the influence of water, the proportion so cut away must represent so many multiples of the fraction of an inch cut away in a decade, and therefore the time that has been since the beginning of the cutting away of that gorge (such as Niagara) is an equivalent number of multiples of the decade of years.

But while this affords an excellent basis for rough estimation, it is not to be forgotten that it acts entirely on the assumption that matter was in those early days as it is now and that the forces are unchanged. This assumption, however useful, cannot be termed strictly scientific, for there is no means of determining whether the original groove, for example, may not have been made in the time when the rock was in a viscous state or even so superheated that water would cause violent fractures, since worn smooth.

The same holds true with sedimentation. A certain land is regarded as being so many thousands or million of years in age because of the rate at which it has been laid down in sediment. But geologists are becoming even more wary of this, especially since the discovery of some coins in a bog in Germany, which, according to the estimates of the laying down of peat, must have been 18,000 years old, and yet which were found to have the stamp of Claudius Cæsar.

The physical argument, moreover, that changes in plants and animals have taken a long while to produce is purely dependent upon a certain theory of variation in biology, a theory by no means certain or approved. Thus, to give the best-known modern instance, in the space of ten years Hugo de Vries, the great Amsterdam botanist, has observed a variation in the Evening Primrose, which is per-

manent and reproductive, yet which according to the older ideas of infinitely slow variation would have been presumed to have taken hundreds, if not thousands, of years. More, if the forces of life were stronger in their youth (as is not an impossible assumption) changes could and probably would occur with greater variety and at higher speeds than at the present time, when the force has been worked over and over for myriad centuries.

An ingenious geological argument has been based by Prof. J. Joly, of Trinity College, Dublin, on the quantity of sodium present in the water of the ocean as a measure of the age of the earth. He assumes that the sodium contained in that water was not derived from the primeval atmosphere or the original constitution of the ocean, but has been supplied in the long course of geological time by the denudation of the land and the consequent removal of the material in solution from the terrestrial rocks. He arrives at the conclusion that if the present annual supply be taken as a measure of what has been the rate in past time, a period of between 90 and 100 millions of years has elapsed since the ocean began to receive its tribute of chemical solution from the land.

The geological argument for the age of the earth may be summed up thus: The geological evidence indicates an interval of probably not much less than 100 million years since the earliest forms of life appeared upon the earth and the oldest stratified rocks began to be laid down.

The physical argument as to the age of this planet is based upon three kinds of evidence: (1) The internal heat and rate of cooling of the earth; (2) the tidal retardation of the earth's rotation; and (3) the origin and age of the sun's heat. (1) Applying Fourier's theory of thermal conductivity, Lord Kelvin pointed out as far back as the year 1862 that the superficial consolidation of the globe could not have occurred less than 20 million years ago, or the underground heat would have been greater than it is; nor more than 400 million years ago, otherwise the under-

ground temperature would have shown no sensible increase downward. He would now restrict the time to between 20

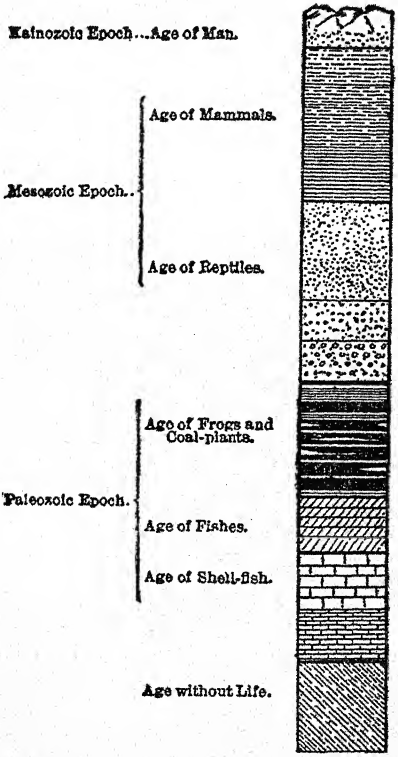

Fig. 41 —Relation of Life to Strata.

and 40 millions. (2) The reasoning from tidal retardation proceeds on the admitted fact that, owing to the friction of the tidal-wave, the rotation of the earth is retarded, and

is therefore slower now than it must have been at one time. Lord Kelvin contends that had the globe become solid some 10,000 million years ago, or indeed any high antiquity beyond 100 million years, the centrifugal force due to the more rapid rotation must have given the planet a very much greater polar flattening than it actually possesses. (3) The third kind of evidence leads to results similar to those derived from the two previous lines of reasoning. It is based upon calculations as to the amount of heat that would be available by the falling together of masses from space, which by their impact gave rise to our sun, and the rate at which this heat has been radiated. Assuming that the sun has been cooling at a uniform rate, Professor Tait concluded that it cannot have supplied the earth, even at the present rate, for more than about 15 or 20 million years. Lord Kelvin also believes that the sun's light will not last more than 5 or 6 millions of years longer.

Believing that "almost anything is possible as to the present internal state of the earth," Professor Perry concluded an article in 'Nature' in these words: "To sum up, we can find no published record of any lower maximum age of life on the earth, as calculated by physicists, than 400 millions of years. From the three physical arguments, Lord Kelvin's higher limits are 1,000, 400 and 500 million years. I have shown that we have reasons for believing that the age, from all these, may be very considerably underestimated. It is to be observed that if we exclude everything but the arguments from mere physics, the probable age of life on the earth is much less than any of the above estimates; but if the paleontologists have good reasons for demanding much greater time, I see nothing from the physicist's point of view which denies them four times the greatest of these estimates."

CHAPTER XIII

THE STORY OF CRYSTALS

THE physicist, as a result of his studies into the structure of different kinds of matter, has concluded that every body is built up of minute particles called molecules, which are much too small to be perceived even by the strongest microscope. When a liquid turns into a solid because the temperature falls, as when water freezes or liquid sulphur or molten iron hardens when cooling, the force of cohesion comes into play to bind these molecules together into a rigid mass. So also, when by slow evaporation from solution, as of salt or alum in water, the dissolving liquid is removed, the substance in solution also passes back into the solid form under the action of this same force of cohesion. Thus the solid is formed from the liquid by the action of the forces acting between these little particles.

Further, if the molecules are all of one kind, as in a given chemical substance, and if there are no hindering causes, these molecules will build themselves up after some regular pattern and the external result is the geometrical form which is called a crystal. This regular building of the molecules, which may take place from a liquid, happens also, even more perfectly, when a solid is formed direct from a gas. Water vapor in the air, if cooled down sufficiently, is formed into the solid snow, and the little snow-crystals that fall silently through the atmosphere are often of wonderful regularity and beauty of form.

In nature it often happens that the building process can-

not go on freely, and imperfect crystals, or perhaps a mass with only a confused crystalline structure, and without distinct external form, is all that is produced. The quartz, feldspar and mica in the rock called granite usually have formed together in such a way that neither one has had an opportunity to build itself up into perfect crystals, and yet the scientist who understands the optical study of thin sections of a rock in polarized light can prove that each grain, formless tho it may be externally, has all the internal molecular structure of the crystal. In the event of a cavity in the granite will be found crystals of quartz and feldspar, perhaps also of mica, as the cavity here means that each has had an opportunity to exercize its tendency to build itself regularly with something of the freedom which a perfect crystal requires.

Another familiar example of crystallization is given by the ice covering a pond, which is as truly crystalline in structure as the perfect snow-crystal; but here there are no crystals, and it is easy to understand why. The slow dissection of the mass, however, under the melting action of the sun reveals something of the regularity in the molecular building, and the same thing is proved by an examination in polarized light. Sometimes in the freezing of a little pool of water the formation of the slender crystalline ribs of ice may be watched as they shoot out, forming a framework which may soon lose its distinctness as the entire surface is frozen over.

Edward S. Dana, in his 'Minerals and How to Study Them,' defines a crystal as "The regular solid form which a chemical substance takes when it passes into the solid state from that of either a liquid or a gas, if under such conditions that the molecules are quite free to arrange themselves according to the direction of the attractive forces acting between them."

The crystal is, therefore, the outward expression of the structure in the arrangement of these molecules, and its form is for this reason the most important of all the physi-

cal character of a given species and the one which in general most definitely distinguishes it from others. "Crystals are therefore," says Professor Dana, "the perfect individuals of the mineral kingdom. The mineral quartz has a specific form and structure, as much as a dog or an elm, and is as distinct and unvarying as regards those characters, altho owing to controlling causes during formation these forms are not always assumed. In whatever part of the world crystals of quartz may be obtained, they are fundamentally identical."

It is interesting to note that a small crystal is just as perfect and complete an individual as a similar one of great size; there is among the crystals of a given species no such connection between size, on the one hand, and age and maturity, on the other, that belongs to the individuals of a species in the animal and vegetable kingdoms. Some crystals are so minute as to be almost microscopic; others may be of enormous size, as the gigantic quartz crystals occasionally found in the Alps, or the equally large beryl crystals from New Hampshire. A cave opened a few years ago at Macomb, New York, contained fifteen tons of great cubic crystals of fluorite; another cave in Wayne County, Utah, contained a great number of enormous crystals of gypsum, some of them three feet or more in length. But the very small crystals and the like ones of enormous size are not essentially different except in this comparatively unimportant respect of magnitude.

It is seldom that any mineral crystallizes alone. Usually two or three, under quite different crystalline laws, form together. "They do this," comments Ruskin, "absolutely without flaw or fault, when they are in fine temper; and observe what this signifies. It signifies that the two, or more, minerals of different natures agree, somehow, between themselves, how much space each will want; agree which of them shall give way to the other at their junction, or in what measure each will accommodate itself to the other's shape. And then each takes its permitted shape

and allotted share of space, yielding, or being yielded to, as it builds till each crystal has fitted itself perfectly and gracefully to its differently natured neighbor.

"This seems to imply both concurrence and compromise, regulating all wilfulness of design; and, more curious still, the crystals do not always give way to each other. They show exactly the same varieties of temper that human creatures might. Sometimes they yield the required place with perfect grace and courtesy, forming fantastic but exquisitely finished groups, and sometimes they will not

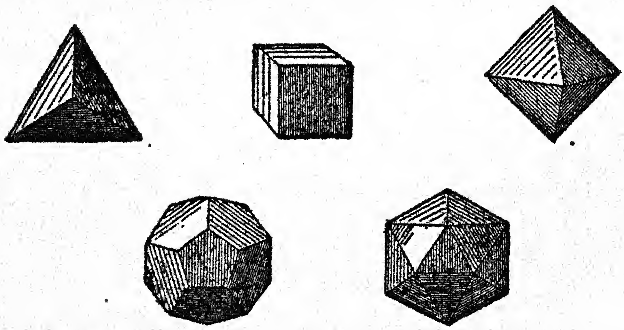

Fig. 42—Simple Forms of Crystal Systems.

yield at all, but fight furiously for their places, losing all shape and honor, and even their own likeness in the contest."

It is an experiment of much ease and great delight to cause the growth of crystals. This may be done by dissolving certain compounds and allowing the solution to evaporate. Let three common substances, which can be found in every home, be used for the experiments—salt, alum and sugar.

First boil some water and add to the boiling water as much of the salt or the alum or the sugar as will dissolve. Pour part of this saturated solution into a saucer, and as

the liquid cools and evaporates, some of the material held in solution will separate out in the form of bright, sparkling crystals on the bottom of the saucer. Meantime keep the rest of the solution hot. Pour this into a glass, and suspend one of the crystals formed in the saucer by a thread in the solution that has been poured into the glass. As this evaporates larger and better shaped crystals will be obtained. The reason for the second group of crystals being in more regular shape is that, in the saucer, in the course of growth, the crystals were flattened by not being able to "grow" equally in all directions. At the same time, the crystals in the glass grow more slowly, and slow growth is conducive to size.

When crystals of salt, of alum and of sugar have thus been secured, a fact of great interest and importance will be made clear. It will be seen that the salt has crystallized in the form of a cube, with six sides; the alum in the form of an octahedron, with eight sides; and the sugar into a tabular crystal, with rectangular outline. You can do what you please with that salt and that alum, but one will remain a cube, the other an octahedron to the end of time.

The next point to keep clearly in mind is that every substance in the world crystallizes in its own way, just as do the salt and the alum. As there is an endless number of minerals and their compounds, there must also be an endless variety of crystals. On the other hand, as crystals follow very definite geometrical laws, there can only be a certain definite number of types or classes. It has been found that there are thirty-two of these, divided into seven systems.

With the best intentions in the world, there are certain subjects which cannot be discussed or explained without the use of some scientific and technical terms. The science of crystals is one of these subjects. A cube, for example, is a technical term. It is so familiar, however, in its shape of a perfect square, like a child's play block, that

one is apt to forget its technical character. In crystallography, it is necessary to keep the shape of the cube well in mind.

Not quite as familiar as the cube, but still fairly easy to understand, is the octahedron. This is a solid, bounded by eight equal-sided or equilateral triangles. It can be easily made thus: Take an apple (as nearly round as possible) and three knitting needles. Thrust one needle through the core from the point of the apple stalk. Stick a second needle through the core from one side to the other. At the point on the circumference of the apple midway between the place where the ends of the last needle protrude, thrust a third needle. Then take a knife and, from the top of the apple, cut off four slices, beginning at the point where the first needle entered at the top, to the points on the surface where each of the other two needles entered the apple. This gives a pyramid effect to the upper half of the apple. Turn the fruit over, and do the same thing from the bottom. The apple will then look like two four-sided pyramids placed base to base. This is an octahedron.

Now, that apple can be divided exactly in half in three ways. It can be sliced in half through the core, beginning from the top, so that the knife will pass through the corners which represent the points where the second needle was inserted. Again, it may be sliced in half by passing the knife from the top through the points which represent where the third needle was inserted. Again, it may be sliced in half through the points where the second and third needles were inserted, not affecting the angles of the first needle at all. Each of these three ways of slicing will leave a four-sided pyramid. In technical terms, then, an octahedron has three planes of symmetry. It is easy to see that a cube can be sliced in half in three different ways, each slice shearing through two of its six facets. There are six other minor planes of symmetry, but, for the sake of simplicity, one may pass on.

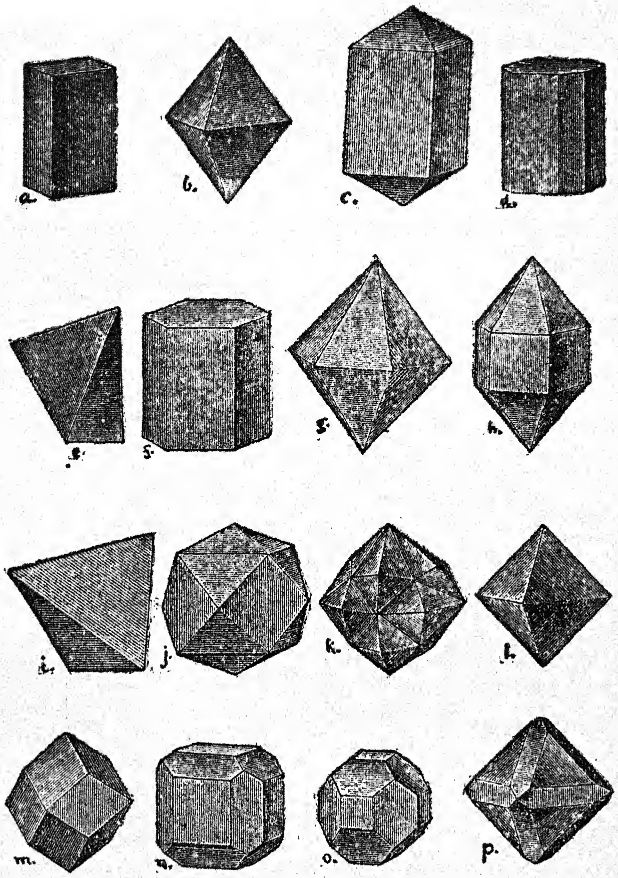

Fig. 43.—COMPLEX FORMS OF CRYSTAL SYSTEMS.

(*a*)—Square Prism. (*b*)—Square Pyramid. (*c*)—Square Prism and Square Pyramid. (*d*)—Combination of two forms of Square Prism. (*e*)—Sphenoid. (*f*)—Hexagonal Prism. (*g*)—Hexagonal Pyramid. (*h*)—Hexagonal Prism and Pyramid. (*i*)—Tetrahedron. (*j*)—Tetrahexahedron. (*k*)—Hexoctahedron. (*l*)—Octahedron. (*m*)—Rhombic Dodecahedron. (*n*)—Cube and Dodecahedron. (*o*)—Cube and Dodecahedron. (*p*)—Octahedron and Dodecahedron.

If either the octahedron or the cube can be rotated on one of its points, it will be seen that four times in the revolution the cube and the octahedron will present the same appearance. This axis is known, therefore, as a tetrad (four-times) axis. It can also be seen that there are three such axes in both the octahedron and the cube. These are the principal axes of symmetry. There are also six more axes of symmetry—four triad (three-times), and two dyad (twice appearing the same).

Just as an example, let us go one step further. Each face of the octahedron intersects all the three axes at equal distances from the center. Now, if a face that intersects two axes at equal lengths, and is parallel to the third, be used, twelve faces can be built up around the cubic axes, and a figure is made with twelve sides, each of the sides being the shape of a rhomb, or lopsided square. This is called a rhombic dodecahedron.

By truncating or cutting off the corners of the cube, an octahedral effect is given. Indeed, to the cube has been added the octahedron, and the figure is now fourteen-sided, and is known as a cubo-octahedron. Its planes and axes of symmetry, then, are similar to the cube and it belongs to the cubic system.

Thus, salt, native copper, iron pyrites, fluor-spar, etc., crystallize in cubes; the octahedron is represented by magnetite and the diamond; and the cubo-octahedron by galena (lead) and smaltite. The garnet crystallizes as a rhombic dodecahedron.

Corresponding to the octahedron, in a second system may be found a solid bounded by eight equal triangles. This is the primary form of a system known as the Tetragonal. In the next system is a solid bounded by eight equal triangles, but in this system (the Orthorhombic) the edges of the triangles are all unequal. In the Monoclinic or oblique system, the crystals possess only one plane of symmetry. In the Anorthic system, all the axes are of unequal lengths and they are all inclined at oblique angles;

there is therefore neither plane nor axis of symmetry, but only a centre of symmetry. In the Rhombohedral system, the primary form is a solid bounded by six equal rhom-shaped faces. The Hexagonal system resembles the Rhombohedral, but, instead of showing a threefold arrangement of faces about a vertical axis, there is a sixfold arrangement.

The growth of crystals is highly irregular so far as outward form is concerned, though the geometrical proportions remain true. Thus some minerals, such as barytes, form table-like crystals; others, like beryl, form columns; and others, again, like sulphide of nickel, form prisms so long and slender that the habit may be called hair-like. Since it is rare that crystals form without interference, nearly all natural crystals are found in confusion, the one forcing the other out of its proper shape. Occasionally two crystals are found together, twinned.

Many minerals, instead of growing as single and distinctly developed crystals, give rise to various kinds of structure or texture, due to the crowding together of a large number of crystal individuals. Loaf sugar to a great degree, and statuary marble to a lesser, show granular crystalline structure, as can be easily seen through a magnifying glass. If the crystalline grains are so small that they cannot be distinguished except under a microscope, then the structure is described as compact and the mineral is said to be massive. A broken surface of this character, except under the microscope, will not show crystalline.

Most of the crystals of minerals would give a very poor impression of nature's workmanship to one who expected always to see them exactly like carefully made models, or like the regular geometrical figures drawn of them. The cubes of galena are often flattened or drawn out. But it is not really to be supposed that the forms are badly made, like a bad model; on the contrary, the size of the like faces on a crystal may vary,

and so the shape of the solid as a whole, but the angles between them remain the same. Moreover, what is really essential is not the size or shape of each face, but the

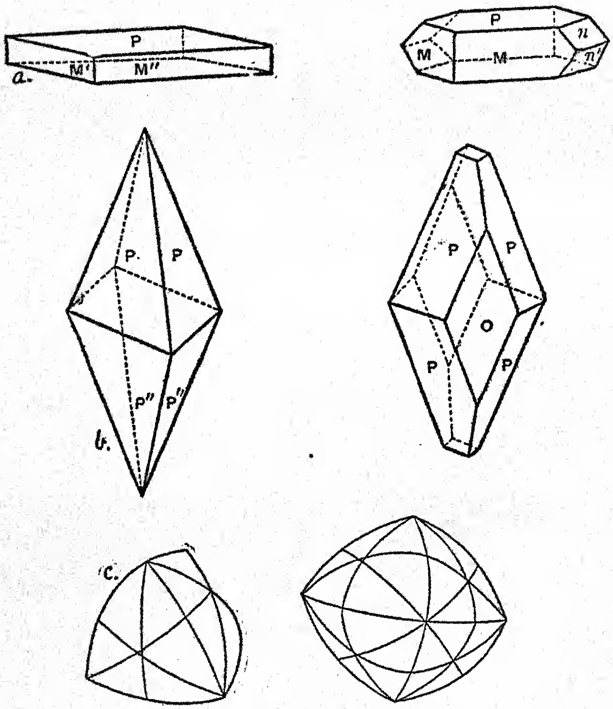

Fig. 44 —NATURAL CRYSTAL FORMS.

(*a*)—Oblique Sulphur; (*b*)—Rhombic Sulphur; (*c*)—Diamond.

way in which the little molecules of which the whole is built up are arranged. For example, in a cube the essential point is the fact that the structure is the same in

the direction of the three cubic faces. It follows from this that in the cube not only are the angles between two adjacent faces always 90°, but the six cubic faces are all similar; and therefore if there is the easy fracture, called cleavage, parallel to one cubic face, there will be also the same cleavage parallel to the others. But the actual size of the faces is a matter of no importance. In fact, in one species the cubes are sometimes lengthened so as to be like fine hairs.

Similar remarks can be made in regard to any distorted form. The symmetry in the molecular structure, and hence the angles between the faces, remain unchanged, altho the symmetry of the external geometrical form is not that of the ideal crystal. A cube may in nature look like a square prism, for the angles between the faces are all right angles in both cases; but the molecular structure of the two is not to be confounded. In the square prism there is the same arrangement in the transverse directions, but a different one up and down; hence the square top of the crystal is not like the four similar oblong vertical faces, and there is cleavage parallel to one set and not to the other.

From this variation it is evident that the practical study of natural crystals is much more difficult than the study of the models which gave the ideal forms. This is especially true because most crystals are so implanted on the rock, or embedded in it, that only part of the form has been developed. Thus quartz crystals are often attached at one extremity, while only the other end has had a chance to grow freely. Or the crystals may be implanted upon a surface of rock so that only a series of minute faces and angles are visible. In such cases the study of the form is really a difficult matter requiring much skill and experience.

Besides the crystals that have been just spoken of, which, while they look at first irregular, are really perfect in the matter of the position of the faces and of

the angles between them, there are others which are really deformed.

Some peculiar condition attending the growth of the crystal, or perhaps some force which has acted upon it since it was formed, has resulted in bending or twisting it out of its normal shape, so that it may differ widely in angle from the regular form. Thus the faces may be curved, as with the barrel-shaped crystals of pyromorphite, or like the peculiar convex faces common on crystals of the diamond; or the whole crystal may be bent, as is seen sometimes in crystals of quartz, stibnite, or of some kinds of chlorite.

Aside from this curving and twisting, a crystal may have had its shape more or less changed by some force exerted in the rock since it was made; it may even have been broken and again cemented together, so that many irregularities may result.

The salt-crystals sometimes show distinctly one face only with the depression in the center, so that they are called hopper-shaped crystals. The cavernous crystals of pyromorphite and vanadinite give other examples. Crystals, often for the same reason, enclose foreign substances, sometimes in the form of liquids, as the quartz crystals that contain water, occasionally with a movable bubble of air. Or the liquid may be carbon dioxide, then often with a bubble of the same substance in the form of gas. In such cases the crystal must have been formed under great pressure, sufficient to keep the gas in the liquid form. Fragments of such crystals heated in the gas-flame fly to pieces with great violence, because of the expansion of the gas formed from the liquid by heat.

A peculiar class of false forms, in which the crystalline shape does not belong to the chemical substance, must be briefly described here. These are called 'pseudomorphs.'

Pseudomorph means false form, and the name is applied to a specimen having the form characteristic of one species and the chemical composition of another. This

seemingly difficult contradiction is easily explained. Most chemical compounds are liable to undergo a change or alteration when subjected to certain conditions, as moisture, the action of alkaline waters or acid vapors. Now, in these cases, if the original mineral was in crystals, the external form is usually preserved, often perfectly, while the chemical nature and the molecular structure have changed.

The cases where the original substance has entirely disappeared and some other has come in to take its place are also called pseudomorphs. Thus occasionally quartz is found in the form of calcite, or of fluorite, or of barite; that is, pseudomorph after one of these; also tin-stone in the form of orthoclase feldspar; native copper in the form of aragonite. Even fossil wood may be said to be a pseudomorph of quartz or opal after the original wood, the structure of which it sometimes preserves with wonderful perfection.

Some crystals occur isolated and alone, and then the form is usually developed on all sides, and with something of the regularity which the ideal model shows. Thus are found perfect garnets in mica schist or granite, and gypsum crystals in clay. But it is still more common to find crystals grouped together either irregularly, as in the majority of cases, or perhaps in parallel position, or again in the peculiar way called twinning.

It is evident that, since the crystals on a single specimen of a species may be grouped in a great variety of ways, it is not always easy to decide whether a given case is a twin or not; this often becomes a matter requiring careful study, exact measurement of angles, and calculation, perhaps also of optical study. For example, it is common to find quartz crystals crossing each other at a great variety of angles, but true quartz twins are rare. The two parts of a true twin are usually symmetrical with reference to the twinning plane, and there is always the reversal of one half.

One very common case of the grouping of crystals, which is apt to be confounded with twinning, is where the crystals or parts of crystals are parallel to each other, so that the axes of all have the same directions, and are not inclined as in most twins. This is illustrated by a pile of cubes with faces parallel and having reëntrant angles between them. The crystals of many species are at times arranged in this way, but in every case it will be found that if the complex group is held so as to reflect the light from a window, the faces in adioining crystals

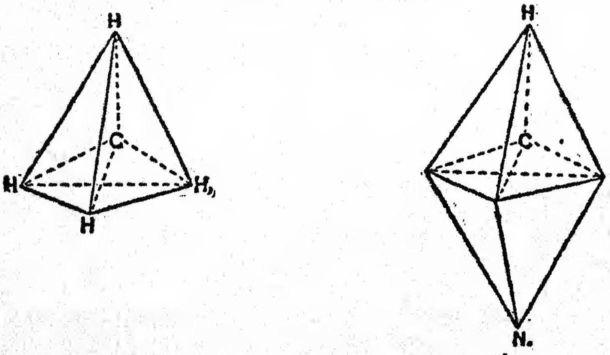

Fig. 45 —FORM OF 'TWINNING' IN A CRYSTAL.

which reflect at the same time are always similar faces. An octahedron of fluorite, built up of a multitude of little cubes in parallel position, is a not very rare example of this.

Parallel grouping is most interesting when the result is to build up a compound form with branching and rebranching parts like the limbs of a shrub or tree, and hence giving rise to a kind of structure called arborescent or dendritic; here all the crystals or parts of crystals have their axes in the same direction. The common method of grouping of crystals, however, is quite irregu-

lar, and it is only exceptionally that twins or parallel groupings are noted.

Minerals are not always in distinct crystals, like those of garnet or quartz, or even in aggregates of crystals. On the contrary, many of the specimens in a mineral cabinet show no crystalline faces at all, and then they are simply called 'massive.' There are, however, important distinctions of structure between massive minerals.

First of all, the distinction between 'crystalline' and 'amorphous' must be well understood. A piece of clear quartz, or rock crystal as it is often called, is said to be crystalline; a piece of glass which very likely the eye alone could not distinguish from it is amorphous or formless. For the mass of quartz, tho it has no definite external form, but is bounded only by irregular fracture surfaces, is just as truly crystalline in structure as a perfect crystal. This is true because the essential idea about a crystallized mineral is that there should be the regular arrangement of the molecules out of which it is built up. It is not always easy, often impossible, with the eye alone to decide whether this regularity of structure exists. It is shown by the cleavage; but when there is no cleavage it is usually by optical examination in what is called polarized light that this can be most easily proved. For example, the bright colors given by a thin fragment of a quartz crystal in polarized light shows at once, to one who understands the subject of optics, that it is crystalline in structure. In the glass, on the other hand, the molecules have no definite arrangement at all, and hence no action on polarized light.

The changes of matter which appear in crystallization, distorted and denuded of their grace as they are often found to be, still reveal great laws which never fail, and to which all change is subordinate, and which appear as such to acomplish a gradual advance to lovelier order, and more calmly, yet more deeply, animated Rest. "Nor has this conviction," says John Ruskin in his somewhat fan-

tastic and humanizing yet graceful 'Ethics of the Dust,' "ever fastened itself upon me more distinctly than during my endeavor to trace the laws which govern the lowly framework of the dust. For, through all the phases of its transition and dissolution, there seems to be a continual effort to raise itself to a higher state; and a measured gain, through the fierce revulsion and slow renewal of the earth's frame, in beauty, and order, and permanence.

"The soft white sediments of the sea draw themselves, in process of time, into smooth knots of sphered symmetry; burdened and strained under increase of pressure, they pass into a nascent marble; scorched by fervent heat, they brighten and blanch into the snowy rock of Paros and Carrara. The dark drift of the inland river, or stagnant slime of inland pool and lake, divides, or resolves itself as it dries, into layers of its several elements; slowly purifying each by the patient withdrawal of it from the anarchy of the mass in which it was mingled. Contracted by increasing drought, till it must shatter into fragments, it infuses continually a finer ichor into the opening veins, and finds in its weakness the first rudiments of a perfect strength. Rent at last, rock from rock, nay, atom from atom, and tormented in lambent fire, it knits, through the fusion, the fibers of a perennial endurance; and, during countless subsequent centuries, declining, or, rather let me say, rising, to repose, finishes the infallible luster of its crystalline beauty, under harmonies of law which are wholly beneficent, because wholly inexorable."

"All crystallization," says the same writer again, "goes on under, and partly records, circumstances of this kind—circumstances of infinite variety, but always involving difficulty, interruption, and change of condition at different times. Observe, first, you have the whole mass of the rock in motion, either contracting itself, and so gradually widening the cracks; or being compressed, and thereby closing them, and crushing their edges; and, if one part

of its substance be softer, at the given temperature, than another, probably squeezing that softer substance out into the veins. Then the veins themselves, when the rock leaves them open by its contraction, act with various powers of suction upon its substance; by capillary attraction when they are fine, by that of pure vacuity when they are larger, or by changes in the constitution and condensation of the mixed gases with which they have been originally filled.

"Those gases themselves may be supplied in all variation of volume and power from below; or, slowly, by the decomposition of the rocks themselves; and, at changing temperatures, must exert relatively changing forces of decomposition and combination on the walls of the veins they fill; while water, at every degree of heat and pressure (from beds of everlasting ice, alternate with cliffs of native rock, to volumes of red hot, or white hot, steam), congeals, and drips, and throbs, and thrills, from crag to crag; and breathes from pulse to pulse of foaming or fiery arteries, whose beating is felt through chains of the great islands of the Indian seas, and makes whole kingdoms of the world quiver in daily earthquake, as if they were light as aspen leaves.

"And, remember, the poor little crystals have to live their lives, and mind their own affairs, in the midst of all this, as best they may. They are wonderfully like human creatures—forget all that is going on if they don't see it, however dreadful; and never think what is to happen to-morrow. They are spiteful or loving, and indolent or painstaking, with no thought whatever of the lava or the flood which may break over them any day; and evaporate them into air-bubbles, or wash them into a solution of salts. And you may look at them, once understanding the surrounding conditions of their fate, with an endless interest. You will see crowds of unfortunate little crystals, who have been forced to constitute themselves in a hurry, their dissolving element being fiercely scorched away; you

will see them doing their best, bright and numberless, but tiny. Then you will find indulged crystals, who have had centuries to form themselves in, and have changed their mind and ways continually; and have been tired, and taken heart again; and have been sick, and got well again; and thought they would try a different diet, and then thought better of it; and made but a poor use of their advantages, after all.

"And sometimes you may see hypocritical crystals (pseudo-morphs) taking the shape of others, tho they are nothing like in their minds; and vampire crystals eating out the hearts of others; and hermit-crab crystals living in the shells of others; and parasite crystals living on the means of others; and courtier crystals glittering in attendance upon others; and all these, besides the two great companies of war and peace, who ally themselves, resolutely to attack, or resolutely to defend. And for the close, you see the broad shadow and deadly force of inevitable fate, above all this: you see the multitudes of crystals whose time has come; not a set time, as with us, but yet a time, sooner or later, when they all must give up their crystal ghosts—when the strength by which they grew, and the breath given them to breathe, pass away from them; and they fail, and are consumed, and vanish away; and another generation is brought to life, framed out of their ashes."

CHAPTER XV

DESCRIPTIVE MINERALOGY.

There was a time when there was no life upon the earth, and, therefore, all matter was mineral. This lifeless period extended through untold ages during which no organic substances were formed, and indeed could not have lived. When, however, the earth's surface became fit for organic introduction life appeared, and thenceforward the mineral matter in earth, water and air began to be acted upon by these new agencies, and the living vegetable and animal forms were produced. Life is continually evolving new forms and substance from apparently lifeless matter, endowing it with properties that in the earlier ages it did not possess, yet all life is based upon the mineral.

In addition to the formation of living organisms from matter, it should be noted that these living organisms contain large quantities of such matter, such, for example, as carbonate of lime, the mineral which constitutes the limestones, the chalks and the marbles, making up the shells of the shell-fish and the calcareous covering of the coral polyp; and consequently, just as the animals owe a debt to the rocks, so quite a large portion of the rocks in the earth has been formed from the mineral remains of plants and animals, only again to be recombined into organic life. Thus it may be seen that in the same manner as there is a 'geographical cycle,' there is also a mineralog-

ical cycle, as the coral polyp takes the mineral calcium from the sea water, and at death returns it to the mineral kingdom. Man is what he is to-day, not only because of the cell-life of his ancestors, but also because of the mineral characteristics of the substances of which they were originally formed.

A mineral has been well defined as a "homogeneous substance of definite chemical composition, found ready-made in nature, and not directly a product of the decay or the life of an organism." It is evident from this

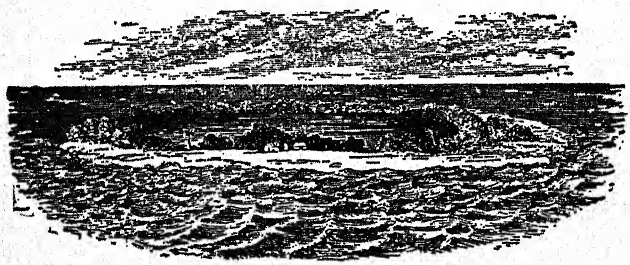

Fig. 46 —Coral Reef.
Cycle from mineral to organic life and thence to mineral again.

definition that the term 'mineral' would apply to an enormous variety of substances. However, only those which possess at least a fair economic importance will be treated in the following pages.

One of the best known and at the same time one of the most valuable of minerals is the diamond. In regard to this stone, E. S. Dana, in his 'Minerals and How to Study Them,' gives the following description: "The diamond is usually found in distinct isolated crystals, most of them very small, but sometimes as large as a robin's egg or even larger. The crystals are commonly octahedrons, though less often some of the other forms of the isometric system are observed. The natural crystals before cutting—

'rough diamonds' they are called—frequently have rounded edges and curved faces, or the faces show little pits. The hardness is higher than that of any other species, and the specific gravity is also high, 3.5. The luster is very brilliant; the brilliancy of the diamond, however, is much greater when cut with many facets than in the natural crystals. The most highly priced stones are colorless, but it sometimes occurs as pale yellow, green, pink or blue. The diamond consists of pure carbon, and has thus the same composition as a piece of charcoal. Diamonds are used for cutting glass and, in the form of powder, in grinding diamonds and other hard gems. The black coal-like diamonds, set in a collar and rotated rapidly by machinery, as a diamond drill, cut quickly through the hardest rocks, leaving a core behind, which is raised at intervals; a well-boring is thus easily made.

Graphite, or plumbago as it is often called, is usually found in massive forms which may be separated easily into thin leaves or plates and hence are said to be foliated; sometimes also it is finely granular and compact. It has the same composition as the diamond, consisting also of nearly pure carbon; it is, however, a different substance in its physical characters and is hence a distinct mineral. Note that they differ in crystalline form; also the diamond is hard and heavy, while graphite is soft and light. Graphite is the so-called black lead of the lead-pencils, but it is only like lead in its color. It is an excellent lubricator because of its smooth soapy character when pulverized; also, mixed with clay it is used for making crucibles because it is infusible and not affected by the heat of an ordinary furnace; in electroplating because it is a conductor of electricty. Carbon is also the element which forms the essential part of the different kinds of coal and of mineral oil or petroleum. Anthracite, the coal of eastern Pennsylvania, contains 85 to 95 per cent. of carbon and has a bright shiny surface and conchoidal fracture; it burns with a pale feeble flame without smoke.

Bituminous coal is black to dark brown in color, often dull and with a pitchy luster; it contains less carbon than anthracite (usually 75 per cent.) and more hydrogen and oxygen; it burns with a yellow smoky flame. Brown coal, or lignite, has a brown color, dull luster, often retains the structure of the original wood and contains still less carbon, sometimes only 50 per cent. These different kind of coal and others related to them, tho of great economic value, are not properly mineral species, since they have no definite chemical composition. The same remark applies to asphaltum, bitumen, mineral wax or ozocerite, the many kinds of mineral resins including amber, and finally mineral oil or petroleum, all of which consist chiefly of carbon.

Sulphur is another of the chemical elements occurring in nature. It is found in crystals of the orthorhombic system; a common form is an acute rhombic pyramid. It also occurs in masses and in powder. It is soft and, tho brittle under the blow of a hammer, is easily cut by the knife; the specific gravity is about 2. It has a resinous luster and a bright sulphur-yellow color and streak. The crystals are often clear and transparent. It is used for making sulphur matches; it is one of the three substances of which gunpowder is made (with charcoal and niter); it is used in preparing the rubber gum for overshoes and other purposes; also in making sulphuric acid and in many other ways.

Altho it cannot be preserved in a mineral cabinet, ice, the solid form of water, is as truly a mineral as diamond or quartz. It occurs in crystalline forms of the hexagonal type, often of great complexity and beauty, as seen in snow-crystals. The ice-grains that make the pellets of hail, not infrequently occurring with summer thunder-storms, are also occasionally in clusters of crystals, somewhat resembling the hexagonal pyramids of quartz, tho this is the exception; generally there is simply a concentric concretionary structure. The ice of the pools and

ponds is always crystalline, tho it is usually only in the first stages of the process of freezing that the crystals are separately visible.

Arsenic is found occasionally as a mineral and then called Native Arsenic. It has a metallic luster and tin-white color, but soon tarnishes on the surface to a dull dark gray; it is also brittle. It is used with copper and tin to form the alloy called speculum metal, useful for metallic mirrors because of the brilliant surface it takes when polished. The lead employed for making shot contains a small amount of arsenic. The compounds of arsenic find various uses, as pigments (sulphide); as a preservative; a poison for insects (white arsenic and Paris green); also in dyeing and medicine.

Antimony, like bismuth, is usually included among the metals, for it has a high metallic luster, altho its structure is crystalline and it is quite brittle. It is a very easily fusible metal and is useful in the arts because of the alloys which it forms with lead and tin, to which it imparts greater hardness and durability. Native Antimony is a bright tin-white mineral with metallic luster, and commonly showing brilliant cleavage surfaces.

Bismuth is silver-white in color with a reddish tinge and has a bright metallic luster; it is rather brittle and shows a crystalline structure with perfect cleavages; it is, however, nearer to the true metals than either arsenic or antimony. Native bismuth is a rare mineral. Some of its alloys have the curious property of contracting instead of expanding with heat. Bismuth is also employed in medicine in the form of the subnitrate; another compound is used as a cosmetic; other uses are in calico-printing and to give luster to porcelain.

Molybdenite is the sulphide of the rare element molybdenum. Like graphite, which it much resembles, it occurs in foliated masses or in crystalline plates having a hexagonal outline; rarely in distinct hexagonal crystals,

It is also very soft, with a soapy feel, and leaves a trace on paper.

Gold is the most highly prized of the metals, valued because it serves as the money of all civilized people, and because of its use for ornaments. It is sometimes found in isometric crystals, as in octahedrons, but usually in plates or scales or wirelike forms; also in larger masses, called nuggets. It is soft and can be cut by the knife. It is highly malleable and ductile and especially remarkable because it can be hammered out into very thin sheets; the skilful gold-beater can make the plates so thin as to transmit a faint greenish light.

Gold occurs mostly in veins in the older crystalline rocks, especially associated with quartz; gold quartz is quartz—often milky—which either shows little particles of gold scattered through it, or from which gold can be obtained—even if not visible to the eye—after the rock is crushed to powder and then washed to remove the lighter material. A large part of the gold of the world has been obtained from the sands and gravels produced by the disintegration of gold-bearing rocks. These gravels in the bed of a stream may be washed by the miner in his pan; or, on a large scale, where a powerful stream of water is thrown against the gravel bank, carrying away the lighter rock and leaving the heavy gold particles behind, usually in the form of little flattened scales.

Platinum is reckoned among the nobler metals with gold, and like it is not attacked by any of the single acids. It has a rather dull gray color, and is not a beautiful metal, altho now more highly valued because of its practical uses than any of the metals except gold. It is rarely found in isometric crystals, as in cubes, more commonly in scales or in larger masses (up to twenty pounds) called nuggets, washed out of the gold sand. The fact that it is fused with great difficulty and is not attacked by ordinary chemical reagents makes it very valuable both to the chemist in the laboratory and in the chemical manufactories,

where crucibles and dishes are made of it. It is also largely used by dentists. It has come into use of recent years for the attachments to the ends of the carbon wire in the incandescent electric lamp.

Silver is one of the precious metals, useful alike as money, for ornaments of many kinds, and for utensils. The color is a fine silver-white when perfectly fresh, but it is easily tarnished, and the presence of sulphur in the atmosphere soon turns it black. Native Silver is not an uncommon mineral, altho the world's supply of the metal comes chiefly from its ores. It is like gold in its occurrence, sometimes, tho rarely, in distinct isometric crystals, more frequently in arborescent or branching groups, in plates and scales or wirelike forms; sometimes in fine threads. It is highly malleable and ductile, and is the best known conductor for both heat and electricity.

Mercury is a remarkable metal, because it is a liquid at all ordinary temperatures, only freezing, or becoming solid, at — 40°. It has a silver-white color and brilliant metallic luster, and is so mobile that from early times it has been called 'quicksilver.' Its density is high, 13.6, or higher than silver (10.6) and lead (11.4), and for this reason and because of its liquid form it is of great value for scientific purposes. It is used in most thermometers and barometers, and is employed in many experiments in the physical and chemical laboratories. It also has the property of forming a pasty mass or amalgam with some of the other metals, as gold and silver (also copper, zinc, tin, etc., but not iron), and is hence of great value in separating them from the rock in which they occur. Ordinary mirrors are made of glass backed with an amalgam of mercury and tin. Mercury in various forms is also used in medicine, but in minute doses, for it is an active poison. Corrosive sublimate is a chloride of mercury.

Native mercury is a rare mineral in nature, tho occasionally found in minute globules scattered through the rock; the common ore is cinnabar, the sulphide of mer-

cury, sometimes called natural vermilion, which is found in masses of a fine red color, and sometimes also in small rhombohedral or prismatic crystals. The luster is adamantine and the color bright cochineal-red, sometimes becoming dull and dark; the streak is scarlet; crystals are usually perfectly transparent.

Copper is one of the most useful of the metals, having been employed for utensils and in other forms, both as a metal and in different alloys, since very early times. Of recent years its use has been increased very largely because of its good conductivity for electricity. It thus forms the material of the wires of the dynamo machines, those by which the electrical current is carried for the electric light, the trolley, etc. Copper is also extensively used for electroplating, as in making stereotype plates. It forms further a large number of useful alloys, of which brass—an alloy of copper and zinc in the ratio of about 2 : 1—is the best known. In the various kinds of bronze (bell-metal, gun-metal, antique and medal bronze, etc.) copper is also the prominent metal, alloyed with tin; in aluminium bronze it is alloyed with aluminium; in german silver it is alloyed with zinc and nickel. Copper is obtained in nature in the native state, and also from a variety of valuable ores, which are some of the most interesting and beautiful minerals.

'Fool's Gold,' Chalcopyrite, or Copper Pyrites, is the beautiful deep brass-yellow copper mineral, often called yellow copper ore. The color is so golden that it is not infrequently mistaken for gold, especially when scattered in small particles through a mass of quartz.

Malachite, the carbonate of copper, is a bright green mineral, often found with native copper, cuprite, and other copper ores because of the readiness with which they are converted into the carbonate by the action of the carbon dioxide present in the air or dissolved in the water. When close and compact it can be cut and polished and thus forms a handsome ornamental stone.

Azurite, or the Blue Carbonate of Copper, is not so common as malachite, but it is also a beautiful mineral, and when in large transparent crystals of a fine deep blue it forms one of the most attractive specimens in a cabinet. The crystals are oblique rhombic prisms.

Lead is one of the most important of the metals, and even pure is used for many purposes familiar to all, as for pipes to convey water and for shot and rifle-balls. It has a dull blue-gray color. It is very soft and malleable. It is often alloyed with other metals; thus with tin in common solder and pewter; with antimony in type-metal; with arsenic in small amount for making shot. White lead (the carbonate) is largely used in making paint, also the oxide, red lead. The supply of the metal, which is used so largely, is obtained from its ores, especially the sulphide, galena. The latter is one of the commonest of minerals, occurring in large deposits in many mining regions. It is also used for glazing common stoneware, and hence it is called potter's ore.

Tin, one of the most important of metals for a great variety of technical purposes, occurs, if at all, only very rarely in nature in the native metallic state. The supply is obtained almost solely from a single ore, the mineral cassiterite, or tin-stone. The use of tin that first suggests itself is for tin plate, so largely employed for vessels, roofing, etc.; this is simply sheet iron coated with metallic tin. Tin enters into many alloys, as the various forms of bronze (gun-metal and bell-metal, etc.), in which it is alloyed with copper; it also forms alloys with lead in pewter and several kinds of solder; with antimony in Britannia metal; with both lead and antimony in Queen's metal, and copper and antimony in Babbitt metal; with lead and bismuth in fusible metal. Cassiterite, or tin-stone, occurs, when crystallized, in square prisms and pyramids and other related forms; twin crystals are common. The crystals have a splendent adamantine luster and a brown color, sometimes nearly black.

Iron may well be called the most important of all the metals. How large a place it takes in the work of the world is shown by the fact that each year some 50,000,000 tons are produced from its various ores and turned into some of the many forms needed by man. The entire supply of iron which the world uses each year is obtained from its ores, in which the iron is in combination chiefly with oxygen. These ores are the minerals hematite, magnetite and limonite; siderite, the carbonate of iron, is also an important ore. The meteorites which occasionally fall to the earth often consist entirely of metallic iron.

Magnetite suggests in its name its most striking character, that of being magnetic. All kinds are strongly attracted by a magnet, and one variety, called the lodestone, found for example at Magnet Cove, Arkansas, is a powerful magnet itself. It has a north and south pole, the power of picking up particles of iron or steel, as tacks, and also, when suspended, it sets with its poles north and south like a compass-needle.

Nickel, tho formerly a little-used metal, has become of much wider application in recent years. It is extensively employed now to plate many articles of steel—as knives, scissors, skates, etc.—because unlike the steel it does not tarnish or rust rapidly in the air. It is much used also, when alloyed with copper, for small coins, as the "nickels" or five-cent pieces of this country, and similarly in Switzerland, Germany and Belgium. Nickel steel has been found to be remarkably strong in withstanding the blow of a cannon-ball. The white alloy called "German silver" contains copper, zinc and nickel in about the proportions of 5:3:2. There are not, however, many minerals which contain nickel. One of these is the sulphide millerite; another is niccolite, or nickel arsenide.

Cobalt is a metal related to nickel and often associated in nature with it in its various compounds, tho of much more limited occurrence. As a metal it is not used in the arts, but its salts, which are most brightly colored, have

some applications. From the change in color that certain of them undergo on heating and on losing water depends their use as sympathetic ink. Cobalt glass, called smalt, has a beautiful blue ultramarine color, and ground up is used as a pigment.

Manganese is a metal which is closely allied to iron in physical characters and chemical relations. As obtained by the chemist—for it does not occur in nature—it is hard and brittle. Like iron, it forms numerous natural compounds, but they do not find many applications in the arts.

Zinc is one of the most common and important of the metallic elements, but it is not certainly known to occur in the form of the metal in nature. It has a crystalline structure like metallic antimony, a white color, and brilliant luster, soon, however, tarnishing. It is brittle at both low and high temperatures, but at 140° Centrigrade it can be rolled into sheets.

It is a most important metal in the arts. Iron in sheets and wire, coated by zinc, are protected from rusting, and are then said to be galvanized; a common use of the sheets is for roofing. Zinc is the negative metal in almost all forms of the chemical electric battery—that is, the metal at the expense of which the electric current is obtained. With copper it forms brass and related alloys; it is also one of the constituents in german silver; an alloy of zinc is used for making raised cuts in photo-engraving. The white oxide is used for paint. Metallic zinc, as obtained from the furnace in ingots, is called spelter.

Aluminium is one of the most remarkable of metals, because while it has great tenacity and is in a high degree sonorous and non-oxidizable in the air, it has a specific gravity of less that calcite, or only 2.5. In other words, it is only about one-third as dense as iron and one-fourth as dense as silver, which it somewhat resembles. Both as the pure metal, because of its low density, and in alloys, for example, with copper as aluminium bronze, because of

their strength and other remarkable properties, it is highly useful.

Corundum, oxide of aluminium, is, next to diamond, the hardest of minerals and one of great interest. Its clear blue varieties make the sapphire of jewelry, and the clear red the highly prized ruby; while the coarse and impure kinds, when pulverized, are emery, used for grinding. The luster, like that of most very hard minerals, is brilliant and adamantine, tho rather dull in some massive kinds. The color is gray to brown or nearly black in many of the common varieties, called in part adamantine spar; bright blue in the variety called the sapphire; red in the ruby; purple in the Oriental amethyst; yellow in the Oriental topaz.

Turquoise, the beautiful precious stone having the color of robin's-egg blue, also bluish green in less highly prized varieties, is a hydrated phospahte of aluminium, containing also a little copper phosphate, which is probably the source of the color. It occurs only in compact massive forms, filling seams and cavities in a volcanic rock.

Calcium, whose oxide (CaO) is the familiar substance called lime, is a white metal somewhat resembling silver or tin. Its compounds are numerous and important, and it is indeed one of the most widely distributed of all the elements.

Fluorite, or Fluor Spar, Calcium Fluoride, is one of the most beautiful of minerals, occurring in cubic crystals and groups of crystals, sometimes very large and of a great variety of colors, from colorless to green, yellow, brown, red and purple. The crystals are usually transparent, and sometimes show on or near the surface a bright bluish color quite different from that observed when they are looked directly through. The blue light extends within the crystal if it is placed in the direct sunlight. This phenomenon is called fluorescence, and having been first observed with fluorite was named accordingly from it.

Calcite, next to quartz, is the most common of mineral species, remarkable for its variety of form both among the

crystallized and uncrystallized varieties. It crystallizes in rhombohedrons and scalenohedrons of great variety and complexity of form, also in hexagonal prisms.

A clear cleavage mass of high-grade calcite, such as that brought from Iceland, is called Iceland spar and is useful for optical prisms. This is because of its remarkable double refraction, or power of dividing a ray of light passing through it into two separate rays, so that a line seen through it appears double.

Besides the crystallized kinds there are those which have a granular struture, as statuary marble, and which sparkle in the light because of the multitude of cleavage-faces. Other kinds are fibrous with a silky luster, like satin spar; also close and compact, as in ordinary marble, and then of great variety of color, red, yellow, blue, black, and largely used for ornamental purposes. Some of these kinds of marble still contain shells, which come out distinctly when polished.

Gypsum occurs in monoclinic crystals; twin crystals are also common. Gypsum also occurs in fibrous forms called, like the similar variety of calcite, satin spar; it is easily distinguished from calcite because so much softer. The luster is pearly on the face of perfect cleavage, otherwise subvitreous; it is also silky in some fibrous forms and in earthy kinds dull. When gypsum is heated and the water of crystallization driven off, Gypsum becomes the anhydrous sulphate. This is done on a large scale and called plaster of paris, which is extensively employed for making plaster casts, for the hard finish for walls, and for other uses. Gypsum is also largely used when ground up for improving soils. The variety alabaster is soft and easily cut into vases and other ornamental objects.

Magnesium is the metal which is present in the oxide (MgO) called magnesia. It is a white metal resembling calcium and closely related to it chemically. In the form of a thin strip or ribbon it burns readily in the air, yielding

a very brilliant white light, which is often used as a source of illumination in photography.

Barium is a metal only known in the laboratory, where is can be obtained from some of its compounds. It is a heavy metal, and takes its name from this fact from the Greek word for heavy (βαρύς). All its salts have also high density.

Strontium is the metal which is present in the various salts characterized by the beautiful red color which they give to the flame. The nitrate is thus used in fireworks and red fire; the hydrate is used for preparing and refining beet-sugar and in extracting crystallized sugar from molasses.

The metals sodium and potassium, tho obtained with some difficulty, are interesting to the chemist because they combine so eagerly with oxygen. For this reason they can be preserved only in some non-oxidizable medium, as oil, and a fragment of potassium placed in water takes fire and burns, uniting with the oxygen and liberating hydrogen; sodium also decomposes water.

Halite, or rock-salt (sodium chloride), is one of the few important minerals which is readily soluble in water and hence gives a decided taste. This taste is familiar to every one, for halite is simply the natural form of table-salt. It crystallizes in fine clear cubic crystals with perfect cubic cleavage; it is also found in granular cleavable masses. It has a vitreous luster, and it is colorless when perfectly pure, but from white it passes through various shades of red and yellow; occasional patches of a deep blue are seen in the clear crystals.

Borax, the sodium borate which is so familiar to the housekeeper, also occurs in nature, and on so large a scale in certain limited regions as to be extensively mined. It is found in monoclinic crystals, often of large size; they are clear at first, but lose water on exposure and become white and opaque. Borax finds many uses in the arts, as in making glass and soap, in soldering and in medicine.

Silicon is, next to oxygen, the most widely distributed of the chemical elements; in fact, it is estimated to make up about one-fourth of the earth's crust. The element itself is known only to the chemist, who obtains it with some difficulty from its compounds; one form is that of reddish crystals, resembling those of the diamond and almost as hard. The common compound of silicon in nature is the oxide, SiO_2, called usually simply silica. The well-known mineral quartz has this composition. Opal is another kind of silica, amorphous and containing some water.

Quartz, the oxide of silicon, is the commonest of minerals, and in some of its varieties one of the most beautiful. It makes up most of the sand of the seashore; it occurs as a rock in the forms of sandstone and quartzite, and is a prominent part of many other important rocks, as granite and gneiss. It is a mineral which can be usually recognised by its form when crystallized; also by its hardness, conchoidal fracture, its glassy luster and infusibility. The color varies widely; crystals are usually colorless or nearly so, but also yellow and brown to nearly black; there are also pink, green and red kinds. The massive forms vary still more, and the color is often in bands or clouds.

Quartz appears under a great number of varieties, differing particularly in color and structure, and as many have long been used for ornamental purposes, they have received a number of distinct names: Rock-crystal, the clear colorless variety; when quite free from flaws it is used for spectacle-glasses, and the Japanese make crystal spheres of rock-crystal; smoky quartz, having a smoky brown color, sometimes very dark. It is cut into ornaments, and in Scotland it is called cairngorm stone. Amethyst, a fine purple kind, also used for ornaments. A yellow variety of quartz crystal is called false topaz; cat's-eye may be mentioned, giving when polished a peculiar effect of opalescence, due to fibers of asbestos, which somewhat resembles the reflection from the eye of a cat; the same name is given to other stones having like effects; the highly prized cat's-

eye of jewelry is a variety of chrysoberyl; chalcedony is a kind having a waxy luster, either transparent or translucent, and varying in color from white to gray, blue, brown, and other shades; agate is a variegated chalcedony, commonly with the colors arranged in delicate parallel bands, straight, curved, or zigzag; onyx is, like much agate, made up of layers of different colors, usually white and black or white and brown, but the banding is straight and the layers are in even planes. The stones may hence be used for cameos, the head being cut from one layer and the background formed by the other; jasper is an impure opaque colored quartz, often red (colored by red iron sesquioxide), also brown or ocher yellow and dark green, sometimes the red and green colors are shown in the same specimen, arranged in bands as in ribbon jasper; and flint, which is nearly opaque and has a dull color, usually gray, smoky brown, and brownish black; it breaks with a deeply conchoidal fracture and a sharp cutting edge, and is hence easily chipped, as by the Indians, into arrow-heads or hatchets.

Opal is a form of silica containing a few per cent. of water. It does not occur in crystals, but in massive and amorphous forms only; these often show a peculiar effect called opalescence, like that of water containing a few drops of milk, and some varieties show a beautiful play of color. The color varies from white to yellow, red, brown, green, gray, and black. It is sometimes transparent, but more commonly only translucent. The most beautiful variety of opal is much admired because of the delicate play of colors, due to the optical effect of internal reflections; the colors are often seen on a white, also on a red, ground. One kind of precious opal with a bright red flash of light is called the fire-opal, and another kind is the harlequin-opal. A beautiful opal found in Queensland shows an iridescent blue sometimes like the effect of a peacock's wing.

Infusorial earth is a kind of opal-silica consisting

of the microscopic shells of the minute vegetable organisms called diatoms, and as found in beds sometimes of great extent is properly ranked as a mineral and a variety of opal; electro-silicon is the trade name of one kind much used for polishing silver: the siliceous shells are so fine that they do not scratch the surface. A layer of pure white infusorial earth is often found under a peat-bed; it would not be easy to estimate the enormous number of the diatom shells that would be required to make up a cubic inch of it.

Beryl is one of those species which are almost always in distinct crystals and usually in forms easy to recognise; it is also interesting because some varieties are used as a gem. The hardness of beryl is 7.5, or a little above that of quartz, and on this account and because of the beautiful color it sometimes has its rank as one of the precious stones. The luster is vitreous or glassy—in this respect also it resembles quartz—and the color is usually some shade of green: bluish green in common beryl, clear mountain-green in the variety called aquamarine, and a deep emerald-green in the highly prized variety emerald. There are also light or dark yellow kinds sometimes having a rich golden color, and occasionally white and, still more rare, pink kinds.

Garnet is another species which, like beryl, is almost always in distinct crystals, and as these crystals are commonly isolated and scattered through the rock, it is not difficult to recognise them. There are, however, massive kinds needing some skill for their identification; these are occasionally used in the same way as emery, tho much less hard. The luster is vitreous, and the color, while most commonly red, varies also from the colorless kinds to those which are yellow, brown, black, and green.

The micas are characterized before all by their very perfect cleavage, in consequence of which they admit of being split into leaves much thinner than a sheet of paper —in fact, it is difficult to set any limit to the extent to

which this process may be carried. These leaves or sheets are usually very elastic and spring back with force when bent. The micas are silicates of alumina with potash, rarely soda or lithia, also magnesia, iron and some other elements.

Chrysolite, or Olivine, is a silicate of magnesia and iron having a vitreous luster and bright yellowish-green color. The luster is vitreous, and the color, besides that mentioned, may be yellow to olive-green and brown. Chrysolite (golden-stone, from χρυσός, gold, and λίθος, stone) is an old term in the mineralogy of former times given to a number of yellow minerals used as gems, thus to beryl, topaz, chrysoberyl and zircon.

Tourmaline is one of the most attractive minerals among the silicates; its varieties show a greater range of color than any other species, not even excepting fluorite, and some of the clear pink and green kinds make beautiful gems. It is almost always found in prismatic crystals, bounded often by three sides, sometimes by six, also by nine, and not infrequently rounded so that there are no distinct faces to be distinguished at all.

Topaz is another gem silicate, beautiful in its fine crystals and in its brilliancy of luster and color. It occurs in prismatic crystals, terminated by rhombic pyramids, sometimes acute, sometimes obtuse. There are also coarse crystals and massive fibrous forms, but these last are not so common. The perfect basal cleavage of topaz is one of its most characteristic points. Hard as it is, it is easily broken in a direction across the prism, and will yield thin plates with very smooth faces. The luster is vitreous, and the color varies from colorless to white, wine-yellow, and blue. Pink topaz is sometimes found.

Serpentine is a remarkable mineral because of the variety of massive forms it assumes, altho it is not known to occur in crystals of its own. The crystals of serpentine which are found are what are called pseudomorphs, having been derived from some other species by chemical

change. The most peculiar variety is the fine fibrous kind called chrysotile (not to be confounded with chrysolite). This usually occurs as thin seams in the massive mineral. Chrysotile may be separated into fibers, very flexible and as soft as the finest silk. This variety is popularly called asbestos, but there is another kind of asbestos of rather similar appearance which is a variety of the mineral amphibole.

These brief descriptions of the principal minerals may serve in some measure to clarify and determine the reader's knowledge of the metals he handles and the stones and rocks whereon he treads, but even so there are fields illimitable of investigation. These might be pointed out in almost any of the minerals, but the question has been so excellently well-worded by Ruskin with regard to marble that it may serve for all. "Another singular point in the business, to my mind," he says, "is that these stones, which men have been cutting into slabs, for thousands of years, to ornament their principal buildings with—and which, under the general name of 'marble,' have been the delight of the eyes, and the wealth of architecture, among all civilized nations—are precisely those on which the signs and brands of these earth agonies have been chiefly struck; and there is not a purple vein nor flaming zone in them, which is not the record of their ancient torture. What a boundless capacity for sleep, and for serene stupidity, there is in the human mind! Fancy reflective beings, who cut and polish stones for three thousand years, for the sake of the pretty stains upon them; and educate themselves to an art at last (such as it is), of imitating these veins by dexterous painting; and never a curious soul of them, all that while, asks, 'What painted the rocks?' "

CHAPTER XVI

MINING AND METALLURGY

AMONG the many minerals which constitute the crust of the earth there are some which are of such character and occur in such quantities that they possess commercial value, and it is profitable to separate them from their neighbors and apply them to the service of mankind. The processes employed in the extraction of these useful minerals are classified under the term "Mining."

The origin of mining retreats into such antiquity as to be most obscure. It is certain, however, that the Phenicians and Egyptians at the earliest periods of history had an abundance of metals. The Egyptians had mines of copper, silver and gold in productive operation both on the Ethiopian and Arabian border. The Sinaitic desert contains the ruins of mining works, probably operated by the Egyptians. Abraham found gold and silver in use among them. In the time of Alexander gold, silver, copper and iron were obtained in Ethiopia. In Asia Minor the gold mines formerly owned by Crœsus were worked down to the time of Xenophon, but Strabo says that in his days they were exhausted. The Athenians worked rich silver mines in Attica and gold mines in Thrace. Before the time of the Romans, mining was carried on in many parts of Western Europe.

After the conquest of Cæsar the tin of Cornwall was shipped first to the Isle of Wight, and thence to the coast of Gaul, where it was loaded upon horses and transported

to Marseilles. The early Romans did not work the mines of their native land, but by their numerous conquests gained control of all the important mines of the ancient world. Traces of ancient mining in the United States are found to the copper region of Lake Superior and to certain districts in New Mexico. In both cases the implements used seem to have been rude hammers of stone.

It is evident that in ancient times muscular force, assisted only by applications of fire and occasionally by the power of water, was the miner's resource. A most suggestive picture of rude mining operations is given in the book of Job, xxviii, 1-11, of which Conant's translation brings out the points very strikingly:

> "For there is a vein for the silver, and a place for the gold which they refine. Iron is taken out of the dust, and stone is fused into copper. He puts an end to the darkness; and he searches out to the very end, stones of thick darkness and of death-shade. He drives a shaft forgotten of the foot, they swing suspended, far from men! The earth, out of it goes bread; and under it is destroyed as with fire. A place of sapphires, are its stones; and it has clods of gold.—Against the flinty rock he puts forth his hand; he overturns mountains from the base. In the rocks, he cleaves out rivers; and his eye sees every precious thing. He binds up streams that they drip not; and the hidden he brings out to light."

Pliny gives a similar description of shaft-sinking operations:

> "Elsewhere pathless rocks are cut away, and are hollowed out to furnish a rest for beams. He who cuts is suspended with ropes.—They go where there is no place for the footprints of man."

The removal of surface material by sluicing was also practiced in ancient times in Spain.

The Aztecs had an extensive metallurgical industry. "They understood how to sink shafts and run tunnels,"

says John S. Hittell, "how to wash gold from alluvial deposits, how to use the bellows and furnace in smelting the ores of copper, tin, lead and silver, and how to cast metals. They had a little tin and considerable quantities of lead." The Quichuans were not less skilful, and they quarried stone with veins of silver on a large scale. They alloyed gold, silver and tin with copper, so that these metals must have been mined, and a complete knowledge of fluxes in the fusion of ores was known to them. Barbarism generally, which is often regarded as being coupled with the Bronze Age, was obviously possessed of mining, and not only of mining. but of smelting also.

Before proceeding with any further discussion of the useful minerals, it is well to understand what is meant by the expression 'ore deposits.' This is clearly set forth by Heinrich Ries in his 'Economic Geology.' "The term ore deposits," he says, "is applied to concentrations of economically valuable metalliferous minerals found in the earth's crust, while under the term 'ore' are included those portions of the ore body of which the metallic minerals form a sufficiently large proportion to make their extraction profitable. A metalliferous mineral or rock might therefore not be an ore at the present day, but become so at a later date, because improved methods of treatment or other conditions rendered the extraction of its metallic contents profitable.

"A few metallic minerals serving as ores, such as gold, copper, platinum, or mercury, sometimes occur in a native condition; but in most cases the metal is combined with other elements, forming sulphides, hydrous oxides, carbonates, sulphates, silicates, chlorides, phosphates, or rarer compounds, the first five of these being the most numerous. A deposit may contain the ores of one or several metals, and there may also be several compounds of the same metal present."

The terms 'rich' and 'poor,' as applied to ores, are used with great frequency, altho most indefinite and often

meaningless. Under very favorable conditions it is possible to profitably work an ore of given value at one locality, while if found under other less favorable conditions at another point it might be almost worthless. The important ore deposits are not numerous. There are many other ores mined for the metal they contain, but they are either of small economic importance or occur in small quantities in nature.

Iron is an abundant constituent of the earth's crust, and yet few minerals are capable of serving as ores of this metal, and five ores supply the greatest amount of the world's iron: Magnetite, Hematite, Limonite, Siderite and Pyrite.

Magnetite occurs in the United States (1) as lenticular masses commonly in metamorphic rocks; (2) as more or less lens-shaped bodies in igneous rocks; (3) as sands on the shores of lakes and seas; and (4) as contact deposits—*i.e.,* those which form along the surface of contact of igneous and sedimentary rocks.

The first class includes the most important deposits now worked in this country. The second and third groups run too high in titanium to have commercial value at the present time, and undoubted representatives of the fourth class of commercial value are not worked. There are some, it is true, which occur along the contact of an intrusive and sedimentary rock, but their origin is ascribed to meteoric circulations.

Of all the iron ores, hematite is by far the most valuable, chiefly on account of its easier reduction, but also because of the greater richness of the known important deposits. Most of the deposits mined belong to the replacement type; that is, they are the result of the replacement of a fissure-filling material.

Limonite may occur under a variety of conditions and associated with different kinds of rocks, but two important types are recognised, viz., bog ores and residual limonites. The bog ores are formed by the precipitation of limonite

in swamps, ponds, or lakes. Such ores are usually impure from an admixture of sand or clay which has been deposited at the same time, and are rarely of any thickness. They are of no commercial value in the United States, but are mined more extensively in Sweden and Canada. The residual limonites are a much more important class, and are formed by the weathering of pyritiferous veins or more often from the weathering of ferruginous rocks.

Siderite is the least important of all the ores of iron mined in the United States, both on account of the small quantity and its low iron contents. When of concretionary structure, with clayey impurities, it is termed clay ironstone. Pyrite, tho widely distributed in nature, is not used as an iron because of the large amount of sulphur contained.

Copper-bearing minerals are not only numerous, but widely altho irregularly distributed. More than this, copper is found associated with nearly every variety of ore or ore deposit. Nevertheless, but few minerals serve as ores of copper. All the largest copper deposits in the world may be divided into two groups: (1) Deposits formed by ascending, circulating, probably hot waters, the ores being deposited in fissures, pores, spaces of brecciation, or sometimes replacement of the rock; (2) pod or lens shaped deposits in crystalline schists, which may represent concentration of material from a disseminated condition in the surrounding rocks.

The ores of lead and zinc occur very often associated with each other. Of these Galena is the commonest lead ore, while others are usually found where superficial oxidation of the deposit has taken place. Of the zinc ores sphalerite (also known as blende, jack, or black-jack) is by far the most important. With few exceptions, zinc is constantly associated with lead, and at times, as in portions of the Cordilleran region, carries silver or even gold.

Gold and silver are obtained from a variety of ores, in some of which the gold predominates, in others silver,

while in still a third class these two metals may be mixed with the baser metals, lead, copper and zinc. Few gold ores are absolutely free from silver, so that a separate treatment of the two is more or less difficult. Gold occurs in nature chiefly as native gold, mechanically mixed with pyrite, or as a telluride such as calaverite.

Most of the gold and silver mined in the United States is obtained from fissure veins, or closely related deposits of irregular shape, in which the gold and silver ores have been deposited from solution, either in fissures, or other cavities, or by replacement. Considerable gold and a little silver is obtained from gravel deposits. Some true contact deposits are known. Gold has been found to occur in rare instances as an original constituent of igneous rocks and also metamorphic ones, but there are no known deposits of commercial value belonging to this type.

The gold and silver ores are sometimes grouped as (1) Placers or gravel deposits; these serve chiefly as a source of native gold, but may and often do contain a little silver, much of which is never separated from the ore in which it occurs; (2) quartzose or dry ores, in which the gold and some silver are found in a quartz gangue, and are either free or mixed with sulphides, commonly pyrite; (3) gold and silver bearing copper ores; these are widely distributed throughout the United States, and exhibit great differences in form and age, neither do all the occurrences yield much gold or silver; (4) gold and silver bearing lead ores; this class includes a variety of deposits, containing much lead, and also silver, with gold usually in subordinate amounts.

Since gold and silver ores so vary in their mineralogical associations and richness, the metallurgical processes involved in their extraction are varied and often complex. Those ores whose precious metal contents can be readily extracted after crushing, by amalgamation with quicksilver, are termed 'free-milling ores.' This includes the ores which carry native gold or silver, and often represent the

oxidized portions of ore bodies. Others, containing the gold as telluride or containing sulphides of the metals, are known as 'refractory ores' and require more complex treatment. These, after mining, are sent direct to the smelter if sufficiently rich, but if not they are often crushed and mechanically concentrated. The smelting process is also used for mixed ores, the latter being often smelted primarily for their lead or copper contents, from which the gold or silver is then separated.

Low-grade ores may first be roasted, and the gold then extracted by leaching with cyanide or chlorine solutions. The introduction of the cyanide and chlorination processes, which are applied chiefly to gold ores, has permitted the working of many deposits formerly looked upon as worthless, and in some regions even the mine dumps are now being worked over for their gold contents.

The Silver-Lead Ores form a large class, which are widely distributed in the Cordilleran region, and not only supply most of the lead mined in the United States, but in addition may also and often do carry variable quantities of silver, gold and copper. The deposits as a whole present a variety of forms. The associated rocks are often faulted, and the ore bodies are commonly oxidized above so that the altered portions require different metallurgical treatment from the sulphide ores found below. Secondary enrichment has in some cases raised the grade of the ore.

Aluminium is one of the few metals whose ores do not present a metallic appearance. Many different minerals contain aluminium, but it can be profitably extracted from only a few. Common clay, for example, presents an inexhaustible supply, but the chemical combination of the aluminium in it is such that its extraction up to the present time has not been found practicable.

While many different minerals contain manganese, practically the only ones of commercial value are the oxides and carbonates, and in this country only the former.

The silicates are not used as a source of manganese, owing to their high silica percentage. The several ores of manganese are often intimately associated, the pyrolusite generally assuming a crystalline and the psilomelane a massive character. Manganese oxides are also often intermixed with more or less oxide of iron, and considerable amounts of the metal are obtained from manganiferous zinc, silver or iron ores. Since much manganese is used in iron reduction, the last association is of importance.

Mercury ores are not confined to any particular formation, but are found in rocks ranging from the Ordovician to Recent Age in different parts of the world. Nor are they peculiar to any special type of rock, altho igneous rocks are often found in the vicinity of them. They occur as veins, disseminations, or as masses of irregular form.

The most important ore of antimony is Stibnite, and the metal is rarely obtained from any other mineral, altho native antimony has been sparingly found. The stibnite, together with a gangue of quartz, and sometimes calcite, usually forms veins cutting igneous, sedimentary, or metamorphic rocks. Antimony has been found at a number of localities in the Cordilleran region, but the great distance of the deposits from the railroad, together with the fact that the smelting plants are located in the East, make them of little commercial value, and no domestic production has been reported since 1901. Moreover, the large output of antimony ores and metal abroad, combined with low ocean freights and the absence of any import tax on crude antimony, are of themselves discouraging to domestic competition.

Nickel and Cobalt can best be treated together, for nearly all the ores containing one are apt to carry some of the other, and furthermore, in smelting, the two metals go into the same matte, and are separated later in the refining process. The nickeliferous Pyrrhotite is the most widely distributed of the nickel ores, and may carry small

amounts of cobalt. It is also called Magnetic Pyrites. The percentage of nickel ranges from a trace to 6 per cent., but an increase above this brings it into Pentlandite.

The ores of Platinum are native platinum and sperrylite. The former is commonly found in placer deposits, but it has also been noted in basic igneous rocks rich in olivine, such as peridotite, or in serpentine derived from it. The sperrylite never occurs in large quantities, but has been found in association with nickel and copper ores. Iridosmine and osmiridium are also known to carry platinum. The nuggets found in placers are often regarded as being pure native platinum; this is only partly true.

The chief ore of Tin is Cassiterite, with 78.6 per cent. metallic tin, but owing to the presence of impurities the ore rarely shows this composition. Its hardness, imperfect cleavage, nonmagnetic character, high specific gravity and brittleness help to distinguish it from other minerals that are liable to occur with it. Stream tin is the name applied to cassiterite found in placers.

Metallurgy is defined as the art of extracting metals from their ores and adapting them to the various processes of manufacture. That this art was practiced in very early times is indicated by references to the use of metals in the oldest written records of the world's history. Among the many stages in the development of primeval man none can have been of greater moment in his struggle for existence than the discovery of the metals and the means of working them. The names generally given to the three prehistoric periods of man's life on earth—the Stone, the Bronze and the Iron Age—imply the vast importance of the progressive steps from the flint knife to the bronze celt and, lastly, to the keen-edged steel weapon or tool.

The metals chiefly used have been gold, silver, copper and tin (the last two forming the alloy called bronze), iron and lead. Of all metallurgical processes, that of the separating of lead from its ores is the oldest. Lead

smelting was known to the ancient Hebrews, and silver ornaments were found on the site of ancient Troy that were so pure as to show that the Trojans know how to separate silver from lead. Lead ores were wrought by the ancient Egyptians perhaps 3,000 years B.C.

The value of iron in ancient times is well brought out by the fact that in Homer's Iliad a mass of iron is mentioned as being one of the prizes at the funeral games of Patroclus.

Metallurgical processes of the present day may be divided into mechanical and chemical. Under mechanical are included the various processes of ore dressing or concentration, the object of which is to separate nearly pure mineral from what is of little or no value.

The methods of extracting metals directly from the crude ore or from the mechanically separated concentrates fall under three classes: (1) Extraction of the metal from oxides and carbonates by the reducing action of carbon and the treatment of sulphides by the oxidation of the sulphur contained; (2) the extraction of a metal by getting it in solution and replacing it by another; (3) amalgamation, or bringing the metal in contact with quicksilver, with which it forms an amalgam. Most metals are obtained ultimately by the use of heat, either by treating the crude ore or the concentrates obtained by some method of ore dressing.

It is well, however, before beginning a discussion of the metallurgy of iron and steel to define just what is the iron and steel of commerce and industry.

In Henry Marion Howe's Iron, Steel and Other Alloys they are described as "composite or granitic substances, intimate mechanical mixtures or conglomerates of microscopic particles of certain quite distinct, well-defined simple substances in widely varying proportions."

The chief of these substances are—

Ferrite, the microscopic particles of nearly and perhaps perfectly pure metallic iron. It is magnetic, very soft and

ductile, but relatively weak, with a tensile strength of about 45,000 pounds per square inch. It is of the isometric system. It always forms a very important part of slowly cooled iron and steel in general.

Cementite, a definite carbide of iron, Fe_3C, containing 6.67 per cent. of carbon, very brittle, harder than hardened steel, scratching glass and feldspar but not quartz, and magnetic. The carbon in slowly cooled steel is chiefly or wholly present as cementite.

Graphite, a characteristic component of "gray cast iron," of which it usually forms from 2 to 3.50 per cent. It is pure or nearly pure carbon. When it forms during the solidification of the metal, as is usually the case, it occurs in very thin laminated plates or flakes, often ⅛ inch or more in diameter. When it forms within the solid metal at temperatures materially below the freezing-point, it occurs, at least under certain conditions, in very fine powder and is then called "temper" graphite, the temper-carbon of Ledebur.

Slag, the characteristic component of wrought iron, which usually contains from 0.20 to 2 per cent. of it. It is essentially a ferrous silicate and is present in wrought iron simply because this variety of iron is made by welding together pasty granules of iron in a bath of such slag, without subsequently melting the resultant mass or in any other way giving the envelopes of slag thus imprisoned a chance to escape completely.

The great classes of iron and steel of chief value to the engineer and probably to the world at large are essentially intimate mixtures or conglomerates of the first two strikingly different microscopic constituents, ferrite extremely soft and ductile, cementite extremely hard and brittle, the former like copper, the latter like glass. The properties of several of the classes may indeed be influenced, and very profoundly, by thermal and mechanical treatment and by the presence in certain of them of slag or of graphite; but the fact on which our attention should be concentrated at

first is this, that the difference in properties between the different industrial classes of iron and steel are due chiefly to differences in the ratio which the ferrite bears to the cementite.

What has just been said does not apply, it is true, to what is called "hardened steel," but it does apply to the great industrial classes of wrought iron and of steel such as ship, rivet, fencing-wire, tube, rail and tin-plate steel and indeed all structural steels, whether for plates, beams, eyebars, angle-irons or any like object.

The steels which are especially soft and ductile—*e.g.*, the rivet and boiler-plate steels—consist chiefly of the soft, ductile, copper-like ferrite, as do those with very high electric conductivity, such as telegraph and telephone wires. In these steels the proportion of cementite may not exceed 1 per cent. of the whole, the rest consisting almost wholly of ferrite.

The harder steels like rail steels, which are called upon to resist abrasion—*e.g.*, the grinding action of the car-wheels intensified by the presence of sand between wheel and rail—have a much larger proportion of cementite. About 93 per cent. of their total mass is made up of ferrite and the remaining 7 per cent. consists of cementite. This quantity of cementite suffices to increase greatly the resistance to abrasion, while the loss of ductility which it causes, tho very marked, is not dangerously great.

Naturally as the proportion of cementite in steel increases and that of ferrite decreases, the ductility diminishes continuously and the hardness increases continuously; the tensile strength, however, reaches a maximum when the cementite amounts to about 15 per cent. of the whole and the ferrite is about 85 per cent.; with further increase of cementite the tensile strength again decreases.

The constitution of steel is not in general reported in the percentages of ferrite and cementite, nor, indeed, are most engineers and metallurgists of to-day sufficiently familiar with this aspect of the subject to speak of it with

confidence. But this is the aspect which the practitioners of the near future must face, and it is also that which makes possible an understanding of the relation between the composition and properties of these different classes of iron and steel. Instead of saying that a certain kind of steel, for instance rail steel, contains so much cementite and so much ferrite, it is customary to report simply the carbon which that cementite represents.

Graphite is an important constituent of cast iron, especially of gray cast iron, but may be regarded as either absent from steel or, if present, only in unimportant quantities.

Gray cast iron, the only kind of cast iron which can be widely used by engineers, may be regarded as a conglomerate of the second degree, for it consists first of a mechanical mixture of ferrite with cementite quite as steel does, while through this mixture as a matrix there is scattered much free carbon in the form of sheets of graphite.

White cast iron typically would consist of cementite and ferrite quite as structural steel does, but with a much larger proportion of cementite, rising even to 67 per cent. (say 4.50 per cent. of carbon). Hence the extreme hardness and brittleness of this class of cast iron, so extreme as to exclude it from most engineering uses.

Wrought iron consists essentially of a metallic matrix identical with low-carbon steel, in which is mechanically mixed a small quantity of slag, a silicate of iron; this slag is not unimportant, yet it is far less important than the ferrite and cementite of the matrix.

Steel hardened by sudden cooling from a red heat consists essentially of austenite, a solid solution of carbon in iron of varying degrees of concentration. When austenite contains as much as 1 per cent. of carbon it is intensely hard and brittle, and indeed its hardness and brittleness are roughly proportional to the quantity of carbon which it contains. Hence steels for purposes which require extreme hardness, such as files and other tools for cutting metals

and even wood, have from about 0.75 to 2 per cent. of carbon, enough to give the degree of hardness required for the special purpose, but not enough to cause a prohibitory degree of brittleness, and they are "hardened" by sudden cooling. Besides the cutting tools, armor-plate and projectiles are made of hardened steel and therefore consist essentially of austenite.

Alloy steels have come into extensive use for important special purposes and a very great increase of their use is to be expected. The chief ones are nickel steel, manganese steel, chrome steel, molybdenum steel and tungsten steel. The general order of merit of a given variety or specimen of iron or steel may be measured by the degree to which it combines strength and hardness with ductility.

Nickel steel, which endures well the effect of sudden shock, is used widely for marine shafting. It has been used tentatively for railroad rails, but while it has the stiffness and resistance to wear which they require, too many rails have broken in use.

As actually made, manganese steel contains about 12 per cent. of manganese and 1.50 per cent. of carbon. Its ductility, to which it owes much of its value, is profoundly affected by the rate of cooling. Sudden cooling makes the metal extremely ductile and slow cooling makes it brittle; its behavior in this respect is thus the opposite of that of carbon steel. Its great hardness, however, is not materially affected by the rate of cooling. It is used extensively for objects which require both hardness and ductility, such as rock-crushing machinery, railway crossings, mine-car wheels and safes.

Chrome steel, which usually contains about 2 per cent. of chromium and 0.8 to 2 per cent. of carbon, owes its value to combining, when in the "hardened" or suddenly cooled state, intense hardness with a high elastic limit, so that it is neither deformed permanently nor cracked by extremely violent shocks. For this reason it is the material generally if not always used for armor-piercing projectiles.

Tungsten steel, which usually contains from 5 to 10 (and sometimes even 24) per cent. of tungsten and from 0.4 to 2 per cent. of carbon, is used for magnets, because of its great retentivity, and for lathe and similar metal-cutting tools which are to cut off a very thick slice at each stroke. The great friction, due to the thickness of the cut, heats the tool to a temperature at which the temper of common or "carbon" steel is drawn. The merit of tungsten steel is that, like manganese steel, it retains its extreme hardness, even after it has been heated to 400° C. (752° F.). Under these conditions the Taylor and White variety retains its cutting power even when the friction is so great that the chips of metal cut are so hot as to glow visibly, and even the edge of the tool itself grows red hot.

Molybdenum Steel is now often used instead of tungsten, 1 per cent. of the former element replacing 2 per cent. of the latter, so that the ratio between their effects appears to be that which their atomic weights would indicate as probable. In other words, one molecule of molybdenum appears to have the same effect as one molecule of tungsten.

To-day practically all of the iron ore mined is smelted in the iron blast-furnace and there converted into cast or pig iron; and this is the case whether the resultant iron is to be used in the form of cast iron or whether it is to be converted into one of the two other great commercial classes of iron, wrought iron and steel. It is true that there are many direct processes by which wrought iron or steel may be made directly from the ore without first converting it into cast iron—*i.e.*, without first putting into it more carbon and silicon than it needs in its finished form and then taking them out at great expense. But these processes are to-day of little more than historical or scientific interest. Whatever promise they may have had in recent decades has been killed by the great cheapening of the blast-furnace process.

The Blast-furnace is an enormous shaft, in many cases as

much as 100 feet high and 25 feet maximum inside diameter. The furnace is at all times full from top to bottom of a column consisting of coke or other fuel, limestone and iron ore, tho the lower part of this column consists of fuel only. The ore, flux and fuel are charged through a hopper at the top of the furnace and form a continuous column extending from the top to the bottom. Through openings called tuyeres at the bottom of the furnace a powerful blast of air, usually highly preheated, is introduced; this burns the

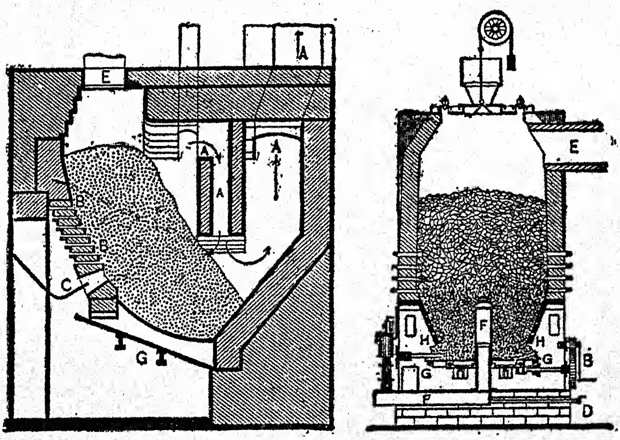

Fig. 47 —Modern Blast-furnace.

fuel, thereby generating an intensely high temperature, sufficient to melt the ore, the iron of which has, by the time it has descended to this region, become reduced to the metallic state. Thus the whole column of solid materials descends slowly as its lower end is eaten away, the fuel which it contains being burned away by the blast and the rest of the material being melted away by the heat from the combustion of this fuel.

In addition to the descending column of solid material

there is an ascending column of hot gases. The oxygen of the blast introduced at the tuyeres is quickly converted into carbonic oxide by its reaction with the carbon of the fuel which it there meets.

Very soon after entering the furnace through the tuyeres the atmospheric oxygen has been converted into carbonic oxide, which, together with the atmospheric nitrogen of the blast, sweeps up through the furnace in enormous columns at great velocity. There is thus two columns moving in opposite directions: a solid column of ore, flux and fuel descending very slowly and a swiftly rising column of hot gases. Any given lump of the solid material passes through the furnace in about 12 to 15 hours, while any given particle of oxygen or nitrogen entering at the tuyeres passes through and quickly escapes at the top, its passage occupying probably only a small fraction of a minute.

The iron ore always contains besides iron oxide a considerable quantity of silicious or earthy material called gangue, and the fuel also contains a certain amount of ash. These materials, the gangue and the ash together with the lime of the limestone, unite to form a single molten mass, the slag, which floats on top of the molten iron. Two deep holes are provided at the lower end of the furnace, one, called the tap-hole, at its very bottom for drawing off the molten iron at intervals, and the other, called the "cinder-notch," a very little above this, for drawing off the molten slag. These holes are closed with plugs of clay, except at the time when the molten materials are drawn through them.

While these two columns, the descending solids and the ascending gases, pass each other, and the hot gas is sweeping up swiftly, the initially cold, solid materials descending slowly, the heat of the gaseous column is recovered by being transferred to the descending solids, so that altho the temperature of the gases in the neighborhood of the tuyeres is above 2,912° F., the temperature of those which

escape from the top of the furnace is only about 572° F. to 752° F. Owing to the fact that the fuel is burned in immediate contact with the solid materials which it is to heat, and that the products of its combustion are thoroly cooled in their long upward travel in which they are exposed to cooler and cooler masses of descending solid materials, the thermal efficiency of the blast-furnace is very high.

The purifying reactions are brought about (1) in the puddling process by stirring iron oxide (in the form of a silicate very rich in that oxide) into the molten cast iron as it lies in a thin boiling layer on the hearth of a reverberatory furnace; (2) in the Bessemer process by blowing cold atmospheric air through the molten cast iron in a deep clay-lined or dolomite-lined retort called a converter, the rapidity of the oxidation itself raising the temperature rapidly; and (3) in the open-hearth process by exposing the molten cast iron in a thin and very broad layer on the bottom of a reverberatory furnace to an overlying layer of slag containing iron oxide, and usually enriched in that oxide by throwing into it lumps of iron ore. In this last process, in addition to this purification of the cast iron by these oxidizing reactions, its impurities are in most cases also greatly diluted by adding much relatively pure steel scrap.

If steel is cooled suddenly it is thereby made harder and less ductile or even extremely brittle and is said to be "hardened." The degree to which it is thus hardened increases with the carbon-content, so that whereas very low-carbon steel is affected only very slightly, steel with 1 per cent. of carbon is made as hard and nearly as brittle as glass.

The hardness and brittleness induced increase with the rapidity of cooling without limit, but they are apparently nearly independent of the temperature from which the sudden cooling begins.

The tensile strength at first increases with the intensity of hardening, but reaches a maximum and then declines. In case of high-carbon steel a moderate rapidity of cooling may give the highest tensile strength, but in case of low-carbon steel the tensile strength seems to increase with rapidity of cooling without limit.

Hardened steel is "tempered"—*i.e.,* the hardening is mitigated or let down, by slight reheating, say to 200° or 300°—and the steel is "annealed"—*i.e.,* the hardening is completely removed, by reheating farther, say to 600°. After this reheating to 200° or 300° it is immaterial whether the steel is then cooled suddenly or slowly; the degree of tempering is the same in either case, and the same is substantially true of the higher heating to 600°, or annealing.

All the best cutlery and tool steel is made by the crucible process, and indeed all for which any considerable excellence is claimed is supposed to be, tho often incorrectly. But the great mass of the steel of commerce is made by the Bessemer and the open-hearth processes, the latter being generally considered the best, and rising from 9 to 53 per cent. in the United States, it reveals in a wonderfully true proportion the advance of progress.